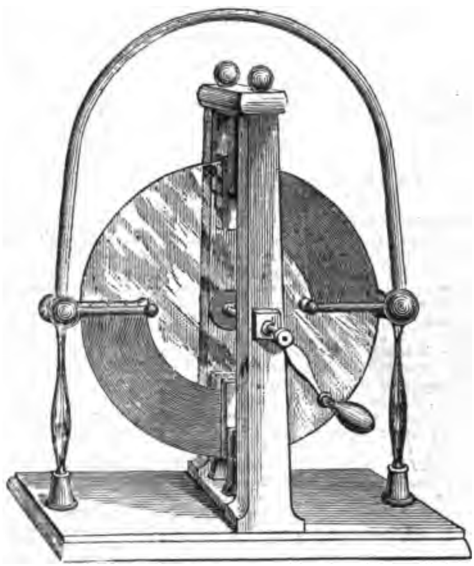
THE ELEMENTS OF

MAGNETISM AND ELECTRICITY.

BY J. C. BUCKMASTER,

Of the Science and Art Department, and Examiner in Chemistry and Physics to the Royal College of Preceptors.



Revised by one of the Examiners.

SEVENTH EDITION.

LONDON:

LONGMANS & CO.; SIMPKIN, MARSHALL, & CO.

DUBLIN: SULLIVAN BROTHERS, 27, MARLBOROUGH STREET.

MANCHESTER: JOHN HEYWOOD.

SCHOLASTIC TRADING COMPANIES; AND ALL BOOKSELLERS.

MDCCCLXXIV

PREFACE TO THE SEVENTH EDITION.

SOME years ago I was encouraged by DR. PLAYFAIR, F.R.S., to write a small Text-book for the instruction of a class in Natural Philosophy. When the subject of scientific instruction was taken up by the Science and Art Department, I endeavoured to make my books useful in facilitating the attainment of sound elementary knowledge in Science. My official work in connection with the Department, now extending over a period of nearly twenty years, has prevented my giving that attention to a revision of the books which from time to time appeared necessary. I felt the best thing I could do was to secure the co-operation and help of the most experienced and successful teachers of the sciences to which the books relate, so as to make them worthy the object for which they have been prepared. I beg also to express my thanks to one of the Examiners, who has kindly revised this Edition.

J. C. BUCKMASTER.

St. John's Hill, Wandsworth, S.W.
October, 1874.

SYLLABUS

ISSUED BY THE SCIENCE AND ART DEPARTMENT.

MAGNETISM AND ELECTRICITY.

First Stage, or Elementary Course.

Magnetism.

It is exceedingly desirable that the pupil's idea of the fundamental facts and principles of magnetism should be as clear as our knowledge and his capacity can make them.

He ought to be made acquainted with the action of the natural magnet or loadstone on small pieces of iron. This is to be mentioned to him as the first fact observed, but for the explanation of which other facts are necessary. The action of two natural magnets upon each other ought to be described, and through this action a clear notion of the doctrine of *magnetic polarity* ought to be conveyed to the pupil's mind.

The power of the natural magnet to confer its own magnetic properties upon steel, and the action of the natural magnet on the steel which it has magnetized, ought to be explained.

The action of two pieces of magnetized steel upon each other ught to be made clear, and from this action the fundamental law, that like poles repel each other and that unlike poles attract each other, ought to be deduced.

The distribution of magnetism on a bar magnet ought to be made clear. The effect of breaking the magnet into two halves; the effect of again breaking these halves; and through facts of this nature, a clear idea is to be conveyed that each molecule of the magnet is itself a magnet; the action of the magnet as a whole being the sum of the actions of its molecules.

It is of exceeding importance that the pupil should be taught to connect the facts of magnetism by means of the provisional conception known as *the theory of magnetic fluids*. The teacher will assure himself that a correct image of this theory is in the pupil's mind. He will at the same time be careful to inform the pupil that the theory is an image merely, which enables him to connect and classify his facts, and that it is not a proved scientific truth.

The theory is to be applied in explaining the difference between iron and steel as regards their power of accepting and retaining magnetism. The term *coercive force*, and all that relates to it, will here come under review.

The theory is also to be applied in explaining the first observed facts of magnetism, including in them, and illustrating by them, the general phenomena of magnetic induction, or magnetization by influence. Every student ought to have a clear image of the state of a piece of iron acted on by a magnet, and he ought to be able to explain why the attraction of the iron is a consequence of that state. He ought clearly to see that repulsion as well as attraction is at work, the resultant attraction being the difference of both.

He ought to understand that when the attracting magnet is very distant, the difference between attraction and repulsion is so small as to be imperceptible; this knowledge will render it easy for him to comprehend why the magnetic poles of the earth which give *direction* to a magnetic needle are incompetent to produce a motion of translation.

The pupil ought to know the facts of terrestrial magnetism; why it is that we consider the earth a magnet. It will be possible to make him acquainted with all that is known regarding the position of the earth's magnetic equator and of the terrestrial magnetic poles.

The terms declination (variation), inclination (dip), and magnetic intensity, ought to be explained to him.

Frictional Electricity.

Here also care must be taken to imprint the fundamental facts and principles clearly and firmly upon the pupil's mind. It is easy in the case of frictional electricity to let the pupil actually see some of the facts; and it is exceedingly desirable that he should do so. The same remark applies to the elementary facts of magnetism.

As in the case of magnetism, the fact first observed, namely, the attraction of light bodies by rubbed amber, must be shown to need other facts for its explanation.

The mode of exciting bodies by friction is to be described: the action of rubbed and unrubbed vitreous bodies upon each other; the action of rubbed and unrubbed resinous bodies upon each other; and the action of vitreous bodies upon resinous bodies, and the reverse, are to be clearly described and illus-

trated. From these facts the law is to be deduced that bodies similarly electrified repel, and dissimilarly electrified attract each other. The pupil ought to know why the term vitreous and resinous, as applied to electricity, have been abandoned.

Having been made acquainted with the elementary facts and principles, the pupil is to be rendered familiar with the provisional conception called the theory of electric fluids. As in the case of magnetism, he is to understand that this theory is an image merely, and not a truth.

He ought to be made acquainted, by experiments performed or described, with the qualities of insulation and conduction. He ought to know the reason of the old division of bodies into electrics and non-electrics, and also the unsound character of this classification.

Clear definitions ought to be given as to what is to be understood by positive and what by negative electricity. The pupil must be able to determine the quality of the electricity with which any body is charged.

He must be thoroughly versed in the phenomena of electric induction, and must be able to apply the theory of electric fluids in the explanation of these phenomena. In connection with the subject of electricity this is the most important part of the teacher's duty, for upon a knowledge of the facts and principles of electric induction the comprehension of almost all that follows it depends.

The pupil ought to be able to construct, or describe the construction of an electrophorus, and to explain its action by reference to the principles of electric induction.

He ought to be able to explain the condenser by reference to the same principles.

He ought to be able to explain the charging and discharging of the Leyden jar by reference to the same principles.

He ought to be able to describe the charging or the prime conductor of an electric machine by reference to the same principles.

The knowledge implied in the last three questions embraces that of the construction of the condenser, the Leyden jar, and the electric machine. The first form of the Leyden jar ought to be known to the pupil.

The distribution of electricity on the surface of conductors is to be made known, and from it the power of points to disperse electricity ought to be deduced. The pupil ought to realize that in virtue of its self-repelling character an electric fluid always

moves to the external surfaces of bodies. The power of flames in dispersing electricity ought also to be made known to the pupil.

He will now be ready to understand the form and theory of lightning conductors.

The physiological, deflagrating, and mechanical effects of the electric discharge ought to be known to the pupil. He ought also to be able to apply his knowledge to the explanation of thunder and lightning, and of the return shock.

Voltaic Electricity.

The simplest combination for the generating of a voltaic current ought to be made known to the pupil. The electric state of the free ends of the two metals immersed in the exciting liquid ought to be described; he ought to be taught to apply the theory of electric fluids to the conception of two currents flowing in opposite directions, and then the omission of one of these currents as a matter of convenience ought to be made known.

It is very important that the pupil should have a clear physical image of the fundamental phenomena before his mind. As in cases formerly referred to, the teacher will be careful to explain that this idea of a fluid flowing in a current is an image merely, and not a proved truth.

Galvani's experiment with the legs of the frog, which he suspended by a copper hook on an iron railing, ought to be explained; and also the experiment of Sulzer, where the tongue is placed between two metals.

The bearing of the experiment illustrating "the return shock" on Galvani's first observation ought to be explained.

The idea of an electro-motive force separating the two electricities and driving them in opposite directions ought to be distinct in the pupil's mind.

He ought to be made acquainted with the magnetical effects of the circuit, with the action of a current upon iron filings, with its action upon a freely suspended magnetic needle. In this latter action he is to be particularly well versed, so as to be able immediately from the deflection of the needle to infer the direction of the current, and from the direction of the current the deflection of the needle.

He must know the action of a current upon a bar of iron placed within a coil round which a current circulates. He must understand the magnetic properties both of the coil and of the bar.

He ought to be made acquainted with the simplest form of the multiplying galvanometer.

He ought to understand the principles of the needle telegraph.

Some of the chemical effects of the current ought to be made known to the pupil. He ought, for example, to have a distinct notion of the composition of water, and an equally distinct notion of its decomposition by the electric current.

SECOND STAGE, OR ADVANCED COURSE.

Magnetism.

The more advanced pupils that undertake the second course ought to be immediately acquainted with all the subjects introduced into the first. The following additional subjects are to be mastered.

The disposition of the so-called magnetic curves round a bar magnet, round two bar magnets with similar or unlike poles adjacent to each other, and round a horseshoe magnet, must be clearly understood. The pupil must know how a short magnetic needle, or a short bar of iron freely suspended acts in relation to those lines, and he must be able to show that the lines are deducible from the doctrine of magnetic polarity combined with elementary mechanical conceptions.

He must be able to figure mentally the magnetic curves of the earth, and to see their relation to the line of dip.

He must have perfectly clear notions as to what is meant by the strength of a magnet. He must be able to compare the strength of magnets together, by the method of oscillation, by the torsion balance, or by the deflection of a small magnetic needle.

A knowledge of the principles and use of the torsion balance is quite essential.

He must know what is meant by the law of inverse squares, and be able to show how it has been experimentally demonstrated.

The pupil must be acquainted with the effect of temperature and of percussion upon a magnet.

He must know the meaning of the terms horizontal intensity, vertical intensity, and total force. He ought also to know what is meant by the variation of all of those, that they are different at different parts of the earth's surface, at different hours of the day, at different seasons of the year. To a knowledge of the diurnal and annual variations he ought to add a knowledge of the secular variation.

Frictional Electricity.

The more advanced pupil must be intimately acquainted with all the subjects introduced into the first course.

He must understand the cascade arrangement of the Leyden battery, as contrasted with the ordinary arrangement.

He must understand the application of the torsion balance to the measurement of electric force.

He ought to be able to think out and describe various new and simple forms of the condenser and the Leyden jar.

He ought to be able to carry forward the idea of an electric fluid to the conception of a current of such fluid; he ought to be able to describe the chemical and magnetical effects of such a current. He ought to be able clearly to contrast those actions as manifested by frictional electricity, with the same actions as manifested by voltaic electricity.

He ought to be able to describe the experimental arrangements necessary to the production of primary, secondary, tertiary, and currents of higher order by the discharge of the electric battery.

He must understand the law of inverse squares as applied to electricity, and clearly comprehend its limitations.

The diurnal variation of atmospheric electricity ought to be known to the pupil.

The application of the unit jar in the measurement of electric charges ought to be known to the pupil.

The terms quantity and intensity (or as it is called by some *density*) as applied to electricity ought to be clearly understood. The relation of the heating power of an electric discharge to its quantity and intensity ought also to be known to the pupil.

Voltaic Electricity.

The more advanced pupil must be intimately acquainted with the subjects mentioned in the first course.

To the electro-magnetical knowledge there demanded he is to add the knowledge of determining the strength of a current by the deflection of a magnetic needle.

He ought also to be able to determine the relative strength of two currents by their chemical action.

He ought to know how the magnetism of a bar of iron augments in intensity as the currents which surround it augment in strength.

He ought to know how the *attraction* of iron by an electro-

magnet augments as the exciting current is augmented. In this case he ought to see and be able to describe the difference between a piece of soft iron and a piece of exceedingly hard magnetized steel.

He ought to be acquainted with induced currents, their various modes of generation, and their laws of action.

He ought to be able to explain the ordinary medical magneto-electric coil. He ought also to be able to describe Ruhmkorff's coil, and some of the effects obtainable by it.

He ought to be able to sketch a current reverser.

He ought to understand the principles of the astatic needle.

He ought to be able to describe the phenomena of the extra current.

He ought to be made acquainted with the mutual action of currents upon each other, with the attractions and repulsions which are dependent upon direction.

He ought to know how a coil of copper wire may be suspended so that when a current flows through the wire it shall, like a magnetic needle, obey the directive action of the earth.

He ought to be acquainted with the principles of electro-plating, adding to a knowledge of the decomposition of water a knowledge of other decompositions, by which conducting surfaces may be coated with copper, silver, or gold.

He ought also to be made acquainted with the chemical actions that occur within a voltaic cell when the current circulates.

The arrangement of cells into batteries ought to be described. The pupil ought to be made acquainted with the *pile* of Volta and the *crown of cups*. He ought also to have explained to him the battery of Grove.

The reason for employing two fluids in the cells of this battery ought to be explained.

The dependence of the heat generated on the resistance overcome by the current ought to be made known. He ought to be taught to form as definite a conception as possible of resistance in relation to electro-motive force, and to understand the formula which expresses the relation of heat, resistance, and current strength.

He ought to understand the theory of molecular currents, and to be able to apply this theory in explanation of the phenomena of magnetism.

EXPERIMENTS IN MAGNETISM AND ELECTRICITY.

The following sketch of experiments, which has been drawn up by Professors Guthrie and Goodeve, is intended to assist teachers in conducting classes in Magnetism and Electricity. It is only to be regarded as an outline. As many of these experiments as possible should be shown to pupils in the "elementary" stage, and all of them to pupils in the "advanced" stage, with as many of those marked (A) as the resources of the teacher will admit.

Preserving this general outline, the teacher should vary and increase the number of experiments to the utmost of his power.

MAGNETISM.

Attraction.—Show attraction by lodestone on iron filings.

Directive polarity of lodestone to the earth and to other lodestone.

Steel capable of permanent magnetization, iron not.

Polarity.—Like poles of needles repel, unlike attract. Either pole attracts soft iron.

Poles.—Break a hard steel spring magnet into lengths, and test the polarity of each.

Determine regions of greatest and least attraction by oscillation of needle.

Determine law of variation of intensity with distance (1) on torsion balance, (2) by oscillations.

Induction.—Compare time of magnetization of steel and of soft iron when in contact with a magnet.

A soft iron bar shifts the pole.

Two permanent magnets placed N. to S. neutralize, and exert little attraction on a soft iron bullet.

Examine the magnetism in a soft iron bar suspended above a permanent magnet.

The greatest possible number of soft iron bullets are suspended from one magnet. Its carrying power is altered by bringing the like or unlike pole of another magnet beneath.

Relation of heat to magnetism.—Destroy the magnetism in a small steel spring magnet by red heat.

A nearly white-hot iron ball is not attracted by a magnet.

Magnetization.—Various methods of magnetization, such as single stroke, double stroke, circular stroke, &c.

Magnetic curves or lines of force.—Parallel bar magnets beneath sheet of glass. Scatter iron filings on glass, tap and print with paper moistened with nut-gall and gum-water.

As above, with like poles in conjunction.

As above, with horseshoe.

As above, with piece of soft iron to be magnetized by induction.

A.—Grove's experiment to show the passage of light amongst oxide of iron suspended in water and surrounded by a coil.

Induction through media.—Examples of attraction and induction through wood, glass, brass, &c.

Diminution through iron.

Magnetism of earth.—Pass a current through a wire wound on a sphere, and compare its magnetism and polarity with that of the earth.

Possible cause of earth's magnetism is a series of currents passing from east to west.

A.—Measurement of intensity of earth's magnetism by magnetometer.

Position of earth's poles.—Declination and inclination.

Compare with needle about bar magnet.

Induction by earth.—A soft iron bar parallel to the lines of magnetic force becomes a magnet.

The lower end of a poker when struck with a hammer repels the end of a needle which points to the north.

A current is established in a closed conductor when it is moved, so as to cut the lines of magnetic force.

A bar of soft iron in a coil in the magnetic meridian, and dip, is connected with a galvanometer and inverted.

Magnetism of iron compounds.—Crystallized sulphate of iron enclosed in a tube, and swung between poles of electro-magnet, sets axially.

A.—Solution of sulphate of iron in a tube swung between the poles of an electro-magnet sets axially.

A.—Powdered dry white sulphate of iron is scattered on black glazed paper above poles of electro-magnet.

Magnetism of nickel and cobalt.—Test.

Pseudo-diamagnetism. — A. — Apparent magnetism due to structure, *e. g.*, short iron wires side by side on wax floating on water. The whole set equatorially.

A.—A number of iron discs separated by cardboard and forming a bar sets equatorially.

Diamagnetism.—A.—A bar of bismuth swung between poles of electro-magnet sets itself equatorially.

A.—A pellet of bismuth is repelled from either pole.

A.—The flame of a candle is split.

A.—The flame of ether is split.

A.—Oxygen charged with chloride of ammonium, vapour assembles round the poles.

A.—Show influence of medium by examining apparent diamagnetism of weak solution of sulphate of iron in a strong one.

FRICTIONAL ELECTRICITY.

Simple attraction.—Amber rubbed with flannel attracts lath balanced on glass flask, also gold-leaf, bran, feathers, &c.

Brown paper (hot) rubbed with a clothes brush attracts as above.

Foreign post paper rubbed with bottle india-rubber attracts as above, also clings to wall.

Silk ribbon rubbed with vulcanized india-rubber, as above.

Collodion rubbed with the fingers, as above.

Glass tube rubbed with electric amalgam on silk attracts as above, also paper roller, egg-shells, &c.

Sealing-wax rubbed with flannel attracts as above.

Stick of sulphur rubbed with flannel attracts as above.

Two kinds of electricity.—Excited glass attracts every unelectrified body, including bar magnet.

Excited sulphur and sealing-wax attract as above.

Excited glass and excited wax attract one another.

Excited glass repels excited glass.

Excited wax repels excited wax.

N.B.—The wax and glass when excited may be placed on little wire stirrups and hung from supports by silk tape.

Foreign post excited with india-rubber is cut into strips forming a tassel.

The two halves of the silk ribbon excited with vulcanized india-rubber repel one another.

Electroscope.—By this instrument test the nature of the electricities in the above experiments, employing proof-plane.

N.B.—Show that the only sure test as to the kind of electricity in the electroscope is the getting increased repulsion.

Nature of surface.—Ground glass rubbed with flannel becomes negatively electrified.

A glass tube held in an alcohol flame becomes negatively electrified.

Conduction.—A glass rod is excited and connected with the electroscope by means of copper, iron, platinum wires, by dry silk, wet silk, cotton, wooden rods, thin sheets or rods of glass (varnished), vulcanized india-rubber, dry paper, &c., &c.

A brass or leaden tube held in the hand and struck with flannel exhibits no excitement.

Held in vulcanized india-rubber or otherwise insulated it does.

Experiments with insulated human body.

Induction.—The electroscope being neutral, approach and withdraw excited glass and sealing-wax.

Entrap + electricity induced in electroscope by separation of conductor from electroscope while under induction.

Entrap – electricity as above, using wax.

Induce + in electroscope by glass rod; connect with earth, remove rod, and test.

Induce – in electroscope as above by wax; connect, &c.

Test the charge at each end of an insulated cylinder under induction.

Connect either end of insulated cylinder under induction with the earth, and prove that one electricity only leaves it.

Construct a semaphore of pith balls on conductor to prove the same.

Light gas by induced free electricity from conductor. Light gas again by withdrawing inducer.

Induce electricity in two spheres, insulated and in contact. Separate them and test their electricities.

A lath rotates by attraction of rod; test the condition of the distant end.

Deduce and illustrate the attraction of all neutral bodies by excited ones.

Electrify surface of varnished glass beaker, and place it over pith balls on metal plate connected with the earth.

Suspend a proof plane and let it vibrate between two oppositely electrified spheres.

Take – electricity by means of a proof plane from the table over which is an excited glass rod.

Condensation.—Brass plate condenser; use.

Make a condenser out of two sheets of tin-foil and a varnished sheet of glass. Connect with electroscope.

Electrophorus.—Make an electrophorus by means of a zinc or tin plate, an isolating handle of sealing wax or varnished glass. A sheet of vulcanized India-rubber or of varnished glass.

Test the electrical state of the excited India-rubber by induction on the electroscope.

Test the free electricity of the zinc plate (1) when in contact, and (2) when touched and withdrawn.

Employ better form of instrument; repeat tests as above.

Experiments with electrophorus, such as lighting gas, exploding mixed gases, &c.

Distribution.—Show the difference of tension on parts of long conductor by means of the repulsion of pith balls. Test also by proof plane and electroscope.

Test by proof plane and electroscope the tensions on different parts of insulated saucepan, flat metallic disc, hat, &c.

Roll up a charged sheet of tin-foil in connection with the electroscope.

Roll up the same placed on a sheet of varnished glass on the table.

Examine the place of the electricity when a charge-insulated ball is clasped between two insulated metallic hemispheres.

Point discharge.—Show rotation of electric wheel.

Chase gold leaf with excited rod.

Gold leaf kite hovering around knob of Leyden jar. The jar preferably uncovered.

Suspended wire with metallic and ordinary paper points to rotate in opposite directions.

Needle on cap of electroscope and prime conductor.

Melted sealing-wax at the end of a needle on prime conductor.

Electrical machines.—Bertsch's machine.

Holtz's machine.

Cylinder machine.

Double plate machine.

A body may be charged either by the addition or subtraction of electricity or by both combined.

Study the method of charging a prime conductor mounted with a point by excited glass or sealing-wax.

Examine the electricities in the prime conductor and rubber.

Leyden jar.—Elementary jar made by two sheets of tin-foil separated by glass.

Single Leyden jar charged and discharged.

Dissected jar.

Partial discharge of Leyden jar from the glass to the inner coating?

Examine the residual charge, primary, secondary, &c.

A jar cannot be charged unless its outer coating is in connection with the earth.

Charge a jar with both positive and negative from the same prime conductor.

Faraday's experiment to show the gradual charging of a submarine cable.

Show cascade arrangement.

Measure capacity of jar by unit jar.

Use of pith ball electroscope.

Charge a jar, insulate it, connect interior with earth, and test exterior.

Experiments with jars.—Construct electric battery.

Deflagrate platinum and silver wire.

Explode gunpowder; show use of wet string.

Burst a tube filled with water.

Light ether.

Discharge through eggs, sugar, ivory, lemon, &c.

Discharge through rarefied air, oxygen, hydrogen, and nitrogen.

Pierce paper.

Duration of spark.—Illuminate by a spark a revolving cross, or coloured disc.

Velocity.—Model of Wheatstone's revolving mirror and apparatus for velocity.

Atmospheric electricity.—Flame on end of fishing-rod connected with the electroscope and isolated.

Examine electricity in steam jet near and some distance from nozzle by conductor and electroscope.

Explain Thomson's electrometer.

Explain and illustrate "return" stroke.

Repel and discharge cotton wool by pointed conductor.

Miscellaneous.—Lichtenberg's figures on electrophorus, varnished glass, ebonite.

Formation of jar by one man standing on insulating stool and grasping another man's hand, a sheet of vulcanized India-rubber intervening.

Test for ozone in brush discharge.

Light gun-cotton by induced spark from flat coil.

Show the effect on astatic needle of friction current from prism conductor.

As above, using—^{ve} electricity.

Change the connections in both above cases with astatic needle.

Connect secondary coil with astatic needle, and show reversal.

Experiment with tertiary coil.

Pyro-electricity.—Tourmaline connected with Thomson's electrometer.

(1.) Heat. (2.) Cool.

VOLTAIC ELECTRICITY.

Connexion between high and low tension electricities.—Deflect astatic needle by selected pairs of metals in salt water, *e.g.*, pin and needle, copper and iron, zinc and lead, &c., and compare with deflection by electricity from prime conductor.

Volta's crown of cups with zinc and copper.

Electric potential at the opposite poles, tested (1) with condenser and electroscope, (2) with Thompson's electrometer.

Condition of the conducting wire.—The copper wire connecting the poles attracts filings. Is heated.

Deflection of magnetic needle by current :—

(1) above needle in direction (1).
(2) ,, ,, ,, (2).
(3) below ,, ,, (1).
(4) ,, ,, ,, (2).

Effect of multiplying coils of conducting wire.—Attraction of filings by coil.

Explain and use astatic needle with feeble currents.

Commutator.—Construct simple form of, and explain commutator.

Helices.—Make models of right and left-handed helices and reversible conical helix.

Magnetism in soft iron by current.—Pass a current across a piece of soft iron :—

(1) in direction 1 above the iron.
(2) ,, ,, 1 below ,,
(3) ,, ,, 2 above ,,
(4) ,, ,, 2 below ,,

Test the poles of the soft iron.

Magnetize a bar of soft iron in a helix by a current.

(1) right handed helix, current direction 1.
(2) ,, ,, ,, ,, 2.
(3) left ,, ,, ,, 1.
(4) ,, ,, ,, ,, 2.

Large hoop coil; introduce soft iron.

Make horse-shoe electro-magnet, and show simple experiments of attraction.

Polarity of coil.—The polarity of the coil is the same as that of the core.

A suspended helix (solenoid) acts as a bar magnet.

A hoop helix and a tube helix are fastened to a bung and floated on acid water, their terminals are of copper and zinc.

They turn N. and S.

The above are attracted and repelled by the poles of a magnet.

Magnets.—A tin tube sucked into a coil.

Electrical machines.—**A.**—Froment's machine.

Increased effect (thermal) by increased number of cells.

Theory of batteries.—Show increase of potential by multiplying the cells.

Diminution of effect by lapse of time with single liquid cell.

Deposition of hydrogen on platinum shown by floating the platinum foil.

Polarity of hydrogenized platinum is the same as that of zinc.

Reuter's pile; silver and flannel.

Devices for the elimination of hydrogen:—

(1) Mechanical; Smee; use of platinized silver.

(2.) Daniell's; substitution of copper for hydrogen.

(3.) Bunsen and Grove; burning of the hydrogen.

Amalgamation of the zinc with mercury.

Electrolysis.—Electrolyze water; examine the proportion and nature of the gases, also their polarity.

Electrolyze salts of silver, copper, lead, &c., using platinum wire electrodes.

Examine the deposition in a drop of solution under the microscope.

Throw focus on screen and shadow of metals during their electrolytic disposition.

Motion of water in direction of current.—In electrolyzing water it follows the current.

Force water through a porous cell and show current by platinum poles in the cell and outside.

Electrolytic measurement of current.—Faraday's voltameter.

Guthrie's voltastat.

Tangent galvanometer:—

Magnetic measurement of current.—Explain laws of deflexion for tangent and zinc galvanometers.

General laws of resistance.—Battery of (n) cells and thin platinum wire.

Send a current round a galvanometer and between two platinum spatulæ in water :—

(1) increased effect by acidification.
(2) ,, ,, approach.
(3) ,, ,, deeper immersion.

Repeat as above, using platinum spiral of thin wire instead of galvanometer.

Introduce into circuit from battery around galvanometer different metal wires :—

(1) Variation with substance of wire.
(2) ,, ,, length ,,
(3) ,, ,, sectional area ,,

Show heating effect of current on compound wire of platinum and silver.

A.—Use of Wheatstone's rheostat.

Ohm's law.—Galvanometer with single hoop of thick wire to be used.

Vary number of cells with no external resistance.

Vary number of cells with large external resistance.

Vary internal resistance by—

(1) varying size of plates.
(2) ,, distance of plates.

Mechanical relations of currents.—1. Currents in same direction attract.

2. Currents in opposite directions repel.

3. Currents crossing one another tend to become parallel.

4. Currents at right angles tend to slide.

5. Ampère's trough and wire to show that one part of a straight current repels the other part.

Induced currents.—1. Setting up current in primary gives reverse in secondary.

2. Cessation of current in primary gives current in same direction in secondary.

3. Approach of primary gives reverse current in secondary.

4. Withdrawal of primary gives same direction of current in secondary.

Ampère's theory of magnetism.—Examine the sliding of a current-bearing wire around a magnet.

(1) Current (1) rotating round north pole.
(2) ,, (2) ,, ,, ,, ,,
(3) ,, (1) ,, ,, south ,,
(4) ,, (2) ,, ,, north pole.

Rotation of a discharge in vacuo around a permanent or electro-magnet.

Examine by galvanometer the current produced through a flat copper coil :—

(1) When placed on north pole of magnet.
(2) ,, ,, south ,, ,,
(3) When taken off north ,, ,,
(4) ,, ,, south ,, ,,

Turn the coil over and repeat.

Magnetize a bar of soft iron while in a coil and examine the direction of current. Vary poles.

Magneto-electric machines.—Simple magneto-electric machine. Decompose iodide of potassium. Heat platinum wire. Heat between carbon points, &c.

Explain Siemen's armature.

Automatic contact breaker.—Explain model of automatic contact breaker.

Ruhmkoff's coil.—Model of dissected coil, shewing—

Discharge through vacuum tubes.

Instantaneous nature of induced current by rotating cross.

Analyze discharge by a rotating mirror or uranium glass.

Formation of ozone.

Induced current in primary or extra current.

Use of condenser.

Further effect of induced current.—Rotation of magnetic needle above a copper disc on the whirling table.

Use of copper plate in compass.

Resistance to motion of conductors in the magnetic field.

Copper saw between poles. Copper coin spun between poles. Copper ring dropped between poles. Same broken.

Applications.—Working model to exhibit the production of oscillatory motion by an electro-magnet. Conversion of this into a Morse and relay.

Wheatstone's needle telegraph and needle relay.

Electric lamp.—Show unequal consumption of poles in air, also in vacuo.

Explain differential motion of poles, and their regulation by a magnet and spring.

Cake silver on negative pole by the projected carbon.

Wheatstone's bridge.—Balance the astatic needle by equal currents.

Interpose unequal resistances produced by variations in length, hickness, temperature, and kind.

Thermo-electricity.—Pairs of different metals, such as zinc, iron,

copper, tin, platinum, silver, bismuth, antimony connected with galvanometer and heated at point of contact.

Cooling produces opposite current.

Passage of current produces heat or cold.

Platinum wire and foil to show that current travels with heat.

Heat one side of tangle in platinum wire.

Further relation between heat and resistance.—Thin platinum wire in alcohol thermometer.

Increased heating of platinum wire when a part is cooled.

Reviews and Notices of Buckmaster's Text-Books.

"The selection good, the explanation clear and intelligible; many persons will find these works very useful."—*Athenæum.*

"We shall be much mistaken if these works do not become recognized class-books among those for whose guidance and instruction they have been written."—*Literary Gazette.*

"Students in elementary science should read these books."—*Saturday Review.*

"In addition to Mr. Buckmaster's long services in promoting the establishment of Science Classes, he has also published some Science Manuals which have been found very useful."—*Speech of Marquis of Ripon, K.G., Feb. 16th,* 1874.

"*School of Mines.*

"The modern ideas of Chemical notation which are met with in the examination papers are no doubt due to the use of your book, which appears well suited to elementary instruction in Chemistry.

"A. W. HOFMANN, F.R.S."

"*Mechanics' Institute, Manchester.*

"I have used your books, especially the 'Chemistry,' in my classes for some time past with decided success and advantage.

"I could mention several larger text-books which contain less information. I hope your books will command the success they deserve.

"JOHN ANGELL."

"*City of London School.*

"Your books have been used in the City of London School with decided success. "DR. MORTIMER, *late Head Master.*"

"*Marlborough House School, Brompton.*

"I have used your 'Chemistry' in my school for some time, and like it very much. "C. SMITH, M.R.C.P."

"*Model Schools, Belfast.*

"I have much pleasure in bearing testimony to the excellence of your 'Acoustics, Light, and Heat;' of a class of fifteen pupils which I held here in connection with the Department of Science and Art, the pupils used no other book, and all passed the May examination. "EDMUND WREN."

"*Science Classes, Christchurch.*

"I have used your 'Elements of Chemistry' as a text-book in my classes during two sessions, and am well satisfied with it. I consider it well adapted to the examinations of the Science and Art Department. I know of no book at the price so good as yours. "W. JUDD, F.C.S."

"*Newtonards Science School, Co. Down.*

"I had your text-book on 'Magnetism and Electricity' supplied to the pupils of my science classes, and have found it of great assistance in preparing them for the May examinations of the Department. The subject-matter is simply and concisely expressed, and so admirably arranged that the pupil who reads it cannot fail to obtain the necessary information. I commend it especially to the pupils of science classes; it affords them a good text-book at a trifling cost. "J. H. GREER."

"*Science School, Leicester.*

"I have long known your work on chemistry, and have used it as a class-book. I feel bound to say, after a fair trial, that I know of no one so well suited for an elementary chemistry class. I am especially pleased with the answers to those questions which require a certain amount of mathematical skill, feeling sure that in the hands of a skilful teacher nothing more is wanted to give a pupil sufficient power to answer any similar questions that may appear in future examinations.

"EDWARD ATKINS, B.SC."

"*Science School, Bolton.*

"I shall require a further supply of your 'Chemistry' for my classes; I have found it admirably suited for its purpose. The 'Physics' contains a capital selection of examples, and supplies at a small cost a text-book which is exceedingly valuable to the student in enabling him to keep pace with the teacher. I have no hesitation in saying that it is the best book I know of at the price. "JOHN COLLINS."

THE ELEMENTS

OF

MAGNETISM AND ELECTRICITY.

MAGNETISM.

MAGNETISM is that branch of physics which treats of the properties of magnets and their action on each other. A natural magnet, sometimes called a loadstone, is the magnetic oxide of iron, Fe_3O_4, and it has the property of attracting certain other bodies. These natural magnets are found in Sweden and Norway, and many places in the United States, especially in Arkansas. The name magnet is probably derived from Magnesia, a town of Lydia, in Asia Minor, where this mineral was found in abundance.

If a natural magnet, no matter what its shape, be rolled in iron filings and afterwards withdrawn, we shall find that the filings are accumulated most abundantly at certain points. These points are poles of the magnet, and are the points of greatest attraction. When either of these points is held at a short distance from the iron filings they will be attracted to it, and adhere with considerable force.

Suspend two pieces of magnetic iron ore by threads,

and bring them nearer to each other; it will be found that they will sometimes attract and be drawn towards each other, at others they will repel. Then on further examination, it will be seen that the same points or poles constantly attract, and that the others as frequently repel. Now allow one piece of stone to assume a position of rest—let the other be removed. The former is under the influence of the earth, and the same end of the stone will constantly be directed to the same portion of the earth; mark the one which points to the north pole of the earth with the letter N, then of course the opposite pole will be the south pole. Now carry out the same experiment with the other piece of loadstone. On again bringing the two pieces together, it will be found that the two ends marked N repel each other. The two south poles do the same; but when a north and a south pole are placed in juxtaposition they attract each other. On this natural fact is founded the following important law:—*Like poles repel, unlike attract.*

These magnetic properties can be easily and permanently imparted to bars of steel; and two steel bar magnets, with one horseshoe magnet, will enable us to carry out many experiments—in short, almost all that are necessary in the science of magnetism. Bars thus magnetized are known as artificial magnets.

Bars of steel and compass needles are usually magnetized by rubbing them with other magnets. The three methods are called magnetizing by *single touch*, by *separate touch*, and by *double touch.*

To magnetize a steel bar by *single touch*, we hold the steel bar or body to be magnetized with one hand. We move along its surface, in one direction one end of a powerful bar magnet. After several repetitions of this process (well raising in the air the bar magnet

at the end) the steel bar will have acquired all the properties of a magnet.

To magnetize a steel bar by *separate touch* we rub the bar from its centre, in one direction, with one pole of a magnetized bar, and in the opposite direction with the opposite pole.

To magnetize a bar by *double touch* two magnetized bars are employed, which are placed with their opposite poles in contact with the bar at its middle point, being only separated by a small interval by a piece of cork or ivory, *Fig.* 1. The bars are then simulta-

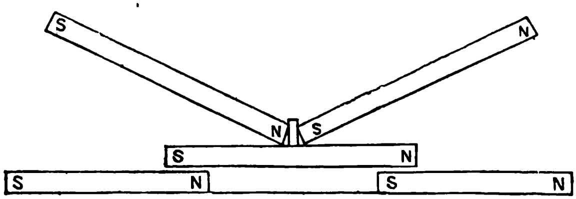


Fig. 1

neously moved first towards one end, and then from this to the other end, and this operation is repeated several times, taking care to finish in the middle. The bars must be kept inclined at an angle of about 30° or 40°, and the same number of strokes must be applied to each half of the bar. The effect is increased by an arrangement of two additional bar magnets as supports for the bar to be operated upon. The poles must be arranged as in the figure.

By far the best modification of the double touch process is that of *divided touch*. Bring the two magnets with their opposite poles in contact down upon the centre of the bar to be magnetized, and then draw then simultaneously in opposite directions from the

centre to the ends, taking them off at these points, and repeating the process twelve or fifteen times on each side of the bar, being careful to rub each end the same number of times. The polarities of the bar will be dissimilar to those of the magnets with which it has been in contact. Horseshoe bars are best magnetized by placing the pole of another horseshoe magnet upon the bend in such a way, that in drawing it to the end only one pole shall pass over each leg,—that is to say, the north pole shall pass down over the leg intended to be south, and the south pole over that intended to be north, the magnet being separated from the horseshoe at the poles. A keeper of soft iron must be kept in contact with the poles of the horseshoe under treatment until the magnetization is completed, and the process must be repeated on both sides.

A Bundle of Magnets consists of a group of magnetized bars united so that the same poles are coincident. Sometimes these bundles are composed of straight bars, and sometimes they are curved in the shape of a horseshoe. Magnets, if left to themselves, lose in time much of their power. Hence it is that armatures or keepers are used. The armature protects the magnet from the enfeebling action of the earth.

This loss of power in bundles is owing to the reaction of similar poles upon each other, by which one reduces the intensity of the other. It often happens that in taking a compound magnet asunder some of the magnets are quite neutralized, whilst others have even had their polarity reversed.

The power of a compound steel magnet is never equal to the sum of its separate elements, but falls very far short of it, but the relative loss being greater in proportion to the number employed.

Cast-iron magnets afford an extraordinary exception

to this rule, their united power often far exceeding the calculated sum of their elements.

Experiments with Artificial Magnets.

EXPERIMENT 1.—Place a sheet of paper on the table, put on a bar magnet, sprinkle iron filings on and around the bar. We shall see that the filings arrange themselves as in *Fig.* 2. From this we learn

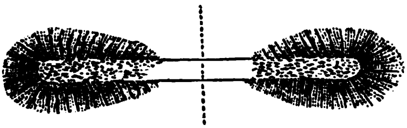


Fig. 2.

that the opposing forces reside in the ends of the bar, that towards the centre they gradually neutralize each other, and that at the centre there is no sign whatever of magnetic power. This is called the neutral point, and every magnet is said to have two poles and a neutral point. When the bar is long and narrow *a series* of poles will sometimes be formed as shown in *Fig.* 3.

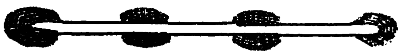


Fig. 3.

EXPERIMENT 2.—Sprinkle iron filings all over the magnetic field, that is, as far as the magnet's influence extends. *Fig.* 4 shows the lines of magnetic force. We see that the filings arrange themselves in curves when under the influence of both poles—thus obeying one of the laws of force. The two opposing

forces impart to the filing curves, which are compounded of the opposing directions in which the forces are employed. Many experiments may be tried with two bars and the filings, such as placing the poles in opposite directions and noting the lines of

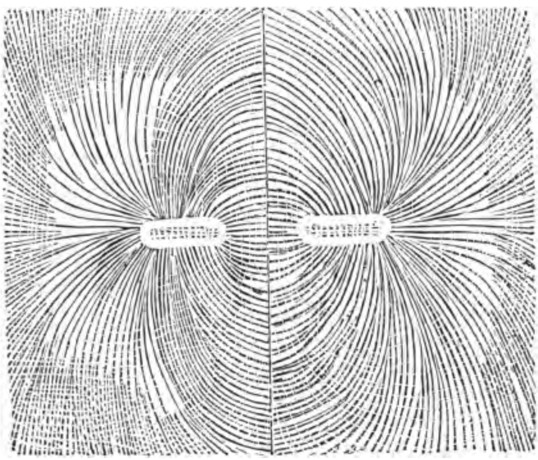


Fig. 4.

force. Then place them in the same direction, &c. On each occasion the student is recommended to draw diagrams of what he sees.

It is necessary, in order to preserve the powers of magnets, to place the opposite poles in connection by means of a soft iron bar. The horseshoe magnet is conveniently arranged for this. Bar magnets are arranged in pairs, with poles in opposite directions, and the ends attached by means of soft bars, or armatures, as they are called. These should be kept con-

stantly attached when the magnets are not in use, and the bars should never lie for any time with the same poles in the same direction, near to each other.

Iron attracted by a magnet reacts on the magnet, and attracts in return; and the same takes place on a bar of iron in which magnetism is induced. It reacts on the magnet which induces the magnetism, and increases its magnetic intensity. From this we have a distinct explanation of the remarkable fact that a magnet has its power increased by having a bar of soft iron placed in contact with one of its poles.

Fig. 5 shows the manner in which the filings would arrange themselves around the poles of a horseshoe

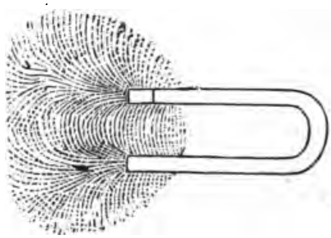


Fig. 5.

magnet. Tapping the paper or table on which the magnet lies favours the distinct formation of the lines.

Experiment 3.—Place a magnetized steel sewing needle on the surface of water in a basin. If not sufficiently buoyant the needle may be pushed through a small piece of cork. With a bar magnet the law that "like poles repel, and unlike attract," may be thoroughly established.

Experiment 4.—Place the bar magnet outside the

basin: it will be found that the magnetism is in no degree diminished by the change. The interposition of glass, or of any other substance, is of no importance, unless that substance is susceptible of magnetic properties,—as, for example, iron.

EXPERIMENT 5.—Again magnetize the sewing-needle, and bring a small piece of iron wire near one of its poles. The wire will attract the magnetized needle, teaching us that the attraction between the magnet and iron is reciprocal.

EXPERIMENT 6.—Float the magnetized needle on the water as in Experiment 5. Note the direction which the point takes when the needle is at rest. Now turn the point in the opposite direction; it will resume its former position, however often you do so, and will rest only in one direction, viz., with its poles or extremities directed nearly north and south. The extremity constantly pointing to the north is called the north pole, and the one that points to the south the south pole.

The experiment may be varied by suspending the needle by means of a thread, or by arranging a flattened needle to work on a vertical pivot, as in *Fig.* 6.

That property which will cause a magnet freely suspended to turn constantly the same extremity towards the same pole of the earth is termed the magnetic polarity or directive power.

EXPERIMENT 7.—Magnetize a long steel needle, ascertain the neutral point, break the needle there, examine the parts, and they will be found to be complete magnets. This will occur however often you may break the parts, showing that every particle of steel is a complete magnet.

Professor Whewell's definition of polarity, before quoted, is beautifully illustrated in magnetism, for if a

flexible steel bar magnetized is bent into the form of a hoop, the poles cannot be discovered. They have completely neutralized each other.

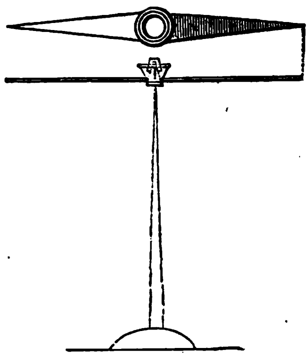


Fig. 6.

Iron and Steel.—If a piece of soft iron wire be suspended by a magnet, through the attraction of one of its poles, the iron becomes magnetic whilst it is in contact with the loadstone ; but if, instead of iron, we use a piece of hardened steel and suspend it, the steel will have acquired a permanent magnetism the strength of which will depend on the power of the magnet to which it is suspended and the length of time it remains in contact. The only substances that can be permanently magnetized are steel and the magnetic oxide of iron, Fe_3O_4, which is the chemical formula of the natural loadstone. Some substances are susceptible of exhibiting certain magnetic properties like those of soft iron, although it is impossible to magnetize them so as to obtain the north and south poles. Nickel is in this manner a magnetic

substance, though it cannot be a magnet. Cobalt also in a less degree, and chromium and manganese, have also been proved to be magnetic.

Theory of Two Fluids.—The hypothesis of two magnetic fluids is advanced to account for the phenomena of magnetism. In a neutral or unmagnetized state a substance is supposed to have the two fluids so arranged as to neutralize each other, but when anything occurs to develop the magnetic properties the fluids separate. One, called boreal or northern magnetism, has the weight of its influence thrown to one part of the substance; and the other called austral or southern magnetism, passes to another part: in a bar the parts would be the opposite ends, which would thus become north and south poles. By this theory, which it must be borne in mind is a *theory* only, the magnetic phenomena may generally be explained. Other and later theories meet with more favour, and notably that of Ampère, which will be given in a later article.

The force required to separate the two fluids in a magnetic body is called the COERCIVE FORCE. The fluids are not separated with equal facility in all bodies. In some—as, for example, in soft iron—they yield easily and separate at once; in others, as hardened steel, the fluids yield with difficulty, and a powerful magnet is required to effect the separation. The harder and better tempered the steel the more difficult it is to separate the two fluids. Soft iron, as we before mentioned, in contact with a magnetized bar becomes a magnet at once, and on being removed returns to its neutral condition. With hardened steel it takes considerable force and some time to render it a magnet, and on being removed from the source by which it became a magnet it continues a magnet.

In order that a body should be made magnetic it is not absolutely necessary that it should be in contact with a magnetized body. The magnetism is communicated, though more feebly, when the two bodies are near each other, but not in contact. For this reason persons carrying valuable watches should never stand near powerful magnets, as the steel arbors of all the wheels are converted into magnets, which attract the steel hairspring and interfere with its free movement.

Magnetic Induction.—If the north pole of a steel magnet, A (*Fig.* 7), be placed near the extremity

Fig. 7.

of a soft piece of iron, B, the end, S, of the soft iron will instantly acquire the properties of a south pole, and the opposite end, N, those of a north pole (the opposite poles would have been produced in the iron if the opposite end, S, of the magnet, A, had been placed near the iron, B); and the iron, although only temporarily magnetic, will render another piece of iron, C, magnetic, and another piece, D; north and south poles being produced at N S and N S. The magnetism in B C and D is said to be induced.

Magnetic induction may then be defined as follows:—"The influence which a magnet exerts upon substances at a distance from it." In making experiments to demonstrate the above facts, it will be observed that if a long piece of iron wire be placed in contact with one of the poles of a powerful magnet, the whole of the wire will possess only one kind of sensible magnetism. It, in fact, becomes a part of the original magnet.

Since magnetic attraction depends upon induction, and there can be no attraction without induction, it follows that the more freely induction can take place, the greater will be the reciprocal attraction between the magnet and the iron. From the experiment just described, if the attractive force between the magnet and the first piece of iron, B, were accurately measured, it would be found to be considerably increased after the application of the second piece of iron, C, and still further increased by the approximation of D.

If we apply three or four pieces of iron alternately, all of equal weights, but of various lengths, to the pole of a magnet, and measure the attraction by a steelyard, the longest pieces will be attracted with the greatest force, the polarity of the same name being prevented from exercising its repulsive influence by its increased distance. Precisely analogous effects are observed in electrical induction.

Magnetic Attraction and Repulsion are the necessary consequences of magnetic induction. The magnet attracts a piece of iron by inducing an opposite polarity at the end in contact with it, and the two opposite principles attract each other. In like manner the north pole of one magnet atracts the south pole of another, and similar poles repel each other, in consequence of the attraction and repulsion of the opposite or similar principles. If, however, the pole of a powerful magnet be suddenly brought near to the similar pole of a weaker one, the inductive action is often so strong as to reverse the polarity of the latter, when attraction, instead of repulsion, will take place. The attraction of iron filings is explained in the same way. Every particle of iron next the magnet has magnetism induced upon it, and it becomes a minute magnet: this particle makes the next particle a magnet;

and so the opposite polarities being induced in each of the particles, they attract one another the same as if they were each permanent magnets. It is not unimportant to notice that at the same time that attraction is at work, repulsion is also performing its part, and that the action shown is not really the full force of either pole, but the remaining power of the attracting pole after it has neutralized the effect of the opposing pole. In bars A and B, whilst the poles N and S adjoining are attracting each other, N is engaged in repelling N, and S in repelling S, while a second attractive force is at work between S and N. For simplicity of illustration we will consider one of each of these forces alone. The attractive force of N and S for each other is predominant because they are nearer to each other than N and N, and the power of this force depends upon this greater distance of S above N. Suppose N and S to be 1 inch apart, and that bar A is 4 inches long; then by the law of inverse squares we shall have a force at 5 inches distance of $\frac{1}{25}$ that at 1 inch. Now suppose that the first distance be 20 inches and the second 21 inches, then by the same law the intensities would be as 400 to 441. The attractive force would only slightly predominate, and would in fact become a directive force only, not having sufficient power to produce a motion of translation. This shows us why the influence of that immense magnet, the earth, upon magnetic needles is so slight as to be unable to do more than exercise a directive force upon them.

Law of Inverse Squares.—The power of a magnet decreases as the square of the distance. At a distance of 1 inch let the power be represented by the number 1, then at 2 inches the power will be $\frac{1}{4}$, at 3 inches $\frac{1}{9}$, &c. (*See Exercises.*)

Strength of a Magnet. Intensity. Method of Oscillations. Torsion Balance.—If weights be attached to the armature of a magnet till it separates we can judge of the power of the magnet. The comparative strength of two or more magnets, or of the parts of a magnet, may be ascertained by noting the number of vibrations made by a small magnetic needle in each case before it assumes a position of rest. The pendulum laws apply to these vibrations. The intensities of the forces are inversely as the squares of the times of the oscillations. This introduces the student to what is known as the *method of oscillations*, and to the use of the Torsion Balance, with which the name of Coulomb will for ever be associated. For the method of oscillation he used a needle whose vibrations, when under the influence of the earth's magnetism, amounted to 15 per minute. Placing a long bar magnet in the magnetic meridian, he brought its south pole to the needle, and found the number of oscillations to be 41 at a distance of 3 inches, and at a distance of 6 inches 24.

$$\text{Now } 41^2 - 15^2 : 24^2 - 15^2$$
$$\text{as } 1456 : 351,$$
$$\text{or as } 4 : 1 \text{ nearly.}$$

That is, by doubling the distance we get a force $\frac{1}{4}$ of the original power at the first distance; the discrepancy being owing to the fact that the experiment could not possibly be made from two *points* only, which would give perfectly correct results.

Fig. 8 represents the Torsion Balance, with which Coulomb demonstrated the laws of magnetism and electricity which are known by his name. The following is the most important of these laws :—

Magnetic attractions and repulsions are inversely as the square of the distance.

The term torsion or twist is applied to this apparatus because its use depends upon the amount of torsion to which a fine wire is subject. It consists of a glass case with glass cover, and an opening, M, through which to introduce the magnet, A. At about the centre of the covering there is another opening, into which is fitted a glass tube. On the top of this

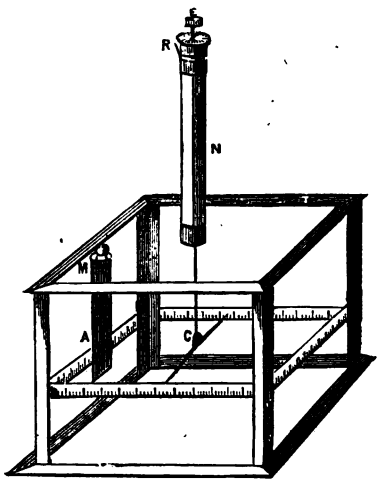


Fig. 8.

tube there is a dial-plate with an index, and the centre pin of this dial supports a very fine silver wire; and this again has a small stirrup, C, suspended, on which magnetic needles may be placed. At the height of the stirrup the glass case is graduated on all four sides. When required for use, place the fixed stop, R, at zero of the disc, and also arrange the case so

that the wire and zero of the scale on the glass case are in the magnetic meridian. Now remove the needle from the stirrup, and replace it with some substance which is not magnetic, say a copper needle; move the tube, N, with its dial-plate until the needle points at zero on the lower graduated scale. Put in the magnetic needle; and, before testing the magnet, A, ascertain the force of the earth's magnetism. Coulomb found that to force the magnetic needle 1° from the magnetic meridian, he must twist the wire 35° on the upper index. Having thus decided the allowance for the earth's magnetism, he next put in the magnet, A, and found that the needle was repelled through 24°. At this time, then, the twist in the wire and the repulsive force balanced each other. This torsion was $24° + (24 \times 35) = 864$. Then the needle was driven back to 12° from the magnet, by means of torsion of the wire given by the screw, E. To do this it was found necessary to turn the index on the upper dial eight times completely round. Now the torsion in the wire, in other words, the repulsive force, is $12° + (8 \times 360 + (12 \times 35) = 3{,}312$.

At 24°, then, the torsion is 864.
" 12° " " 3,312.

That is, at one-half the distance the force is four times as great. (*See Exercises.*)

TERRESTRIAL MAGNETISM.

The Mariner's Compass.—This, it is well known, is a magnetic needle in a circular box made of brass or copper. The needle is attached to a card

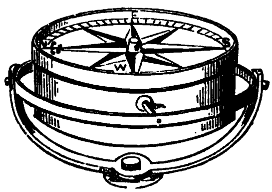


Fig. 8*.

on the under side generally, and the card moves with the needle; so that it is only necessary to see that the needle is fitted with its north pole to the marked north of the card, and the remainder of the thirty-two points of the compass, or rhumbs, as they are sometimes named, will all be in true position. The box is supported by means of two concentric hoops, called gimbals, so arranged that whichever way the ship may roll, the card preserves its horizontal position. In a land compass the card is fixed at the bottom of the box, and the needle moves over its surface. This is commonly used by travellers and surveyors for determining the different points of the horizon. It is noticed that in the northern hemisphere the north pole of the needle has a tendency to dip down, and in the southern hemisphere the south pole shows the same inclination. To remedy this a small weight is placed on the higher end of the needle, so that it may preserve its horizontal position and work freely. Of course this weight must be moved according to the ship's position on the ocean. If we obtain a needle

which is suspended so as to move vertically, then this dip will show much more clearly. In the neighbourhood of London the dip is now about 68°, and is called the angle of dip or inclination for London. *Fig.* 9 represents a dip needle, and the angle refered to is

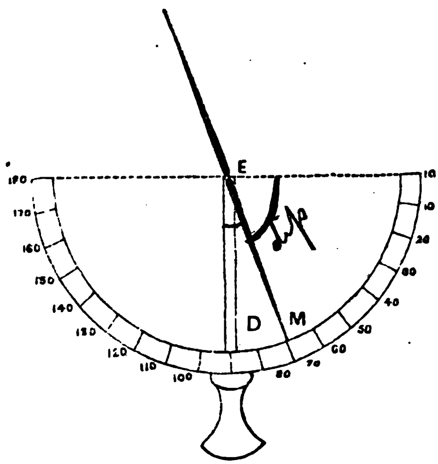


Fig. 9.

angle M E D. Further north this will become larger, until at the north magnetic pole it will be 90°, and the needle will become vertical, with its north pole downwards. As we go further south in the northern hemisphere the angle will become less and less, until near the equator the needle will be perfectly horizontal. A line connecting all the points round the earth where this would occur is called the magnetic equator. Travelling further south, the south pole of the needle would

undergo corresponding changes until we reach the south magnetic pole, where the needle would again assume a vertical position. The teacher may illustrate this with a large sewing-needle magnetized, put through a cork, and another needle or a piece of copper wire passed through the cork at right angles, with its ends supported, but quite free to move. By placing a suspended magnetic needle over a bar magnet, all the

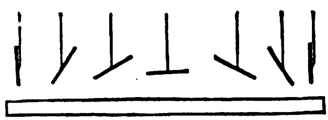


Fig. 10.

above positions may be distinctly shown, as in *Fig.* 10.

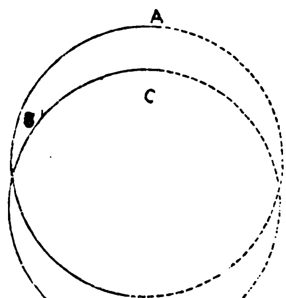


Fig. 11.

Meridians.—A geographical meridian is a great circle passing through the north and south poles around the earth from some given position. A mag-

netic meridian is a great circle passing through the magnetic needle when in its true position of rest, and through the magnetic poles round the earth. These meridians sometimes coincide, but the place and time of coincidence is ever varying. It has been found that there is a line passing round the earth where this coincidence occurs, called the line of no variation or declination; in any other part of the earth's surface the two circles cross each other, making an angle, A B C, as in *Fig.* 11. This is called *the angle of variation or declination;* it increases as we travel east or west from the line of no variation, until it reaches a maximum, then decreases to 0° when again arriving at this line. When the north pole of the needle points to the east of true north the declination is said to be east; when to the west of true north it is said to be to the west. The line of no variation runs from 60° to the west of Hudson's Bay, in a southerly direction through the American lakes to the West Indies, through Cleveland, to near Charleston, just touching the easternmost part of South America, and crossing the Antarctic Ocean, reappears in the West of Australia, crosses India, goes through the Caspian Sea to the White Sea, completing a circle round the earth. The line of no declination is moving gradually westward. Beside this slow change, the magnetic needle undergoes others, some of which are regular and some irregular. In our latitude the north end of the needle is moving slowly towards the west during the early part of the day, and back again during the latter part of the day. This is called the diurnal variation. In the southern hemisphere the motion is reversed. There is also a small change of a similar nature which takes place annually, called the annual variation.

The secular variation is a term applied to a variation which it takes several centuries to observe. For example, the angle of variation at Paris in—

1663	was	0°.
1814	„	22° 34′ W.
1850	„	20° 30′ W.
1865	„	18° 44′ W.

So that it is to be observed that the angle of declination in this country is gradually decreasing; and, although it is at present W., yet in the course of two or three centuries it will probably be east. Irregular changes are called perturbations. They take place during a thunderstorm, aurora borealis, and during any sudden change in the electrical condition of the atmosphere.

The two Magnetic Poles of the Earth are situated in the vicinity of the poles of the earth's axis, and are called the magnetic north pole and the magnetic south pole. These contrary poles attract each other, and thus a magnetic needle will turn its south pole to the north and its north pole to the south. What we call the north pole of the needle is in fact its south pole, for like poles repel, therefore the north pole of the earth would repel the north pole of the needle.

The exact position of the northern magnetic pole is in 96° 43′ W. long., and 70° N. lat. It was visited by Sir J. Franklin and Sir J. Ross in 1832. The south magnetic pole is in the antarctic continent, 154° E. long., 75° 30′ S. lat., and has been approached within 170 miles. If an ordinary compass be carried to either of these poles it will lose its power, and point indifferently in any direction. If it be carried beyond the magnetic pole to any point between the true pole of the earth and the magnetic

pole, the needle becomes reversed, the end called the north pointing to the south, and the end called the south pointing to the north.

As the directive tendency of the magnetic needle arises from its poles being attracted by those of the earth, it is clear, from the rotundity of the earth, that its poles will not be attracted by those of the earth horizontally, but downwards, so that the needle cannot tend to be horizontal, except when both its poles are acted upon equally, and that is when it is midway between them. Accordingly, a needle which balanced, without difficulty, before it was magnetized, will no longer balance itself when magnetized. This dip is corrected, as we before mentioned, in ships' compasses by a small sliding weight, which has to be removed as the ship moves towards the equator, and placed on the opposite end of the needle when in another hemisphere.

It is this tendency to dip which is the cause of the want of stability in the compass needle during a storm. The sliding-weight which is placed to counteract the dip, and bring the needle to a horizontal position renders the arms of unequal weights.

During the rolling of a ship, the heavier arm acquires the greater momentum, and in the change of motion this momentum opposes the force acting on the centre of the needle, and, not being counterbalanced by an equal momentum at the other end, it causes the needle to swing more and more at each roll, until at length the needle makes an entire revolution and becomes useless.

Terrestrial Induction.—A body capable of being magnetized may be converted into a magnet by the inductive influence of the earth, or more rapidly by being rubbed with a natural magnet. Natural

magnets owe their magnetism to the slow induction of the earth. If we place a thin bar of iron in the magnetic meridian, and incline it to the horizon according to the angle of the dip, the earth acts upon it by induction. The magnetism thus induced is only temporary, for if the bar be removed from its position the effect disappears. A steel bar similarly placed does not, on account of its coercive force acquire such induced magnetism so readily, unless the coercive force is temporarily disturbed by vibrating the rod by blows with a hammer.

These properties of taking on polarity by position, and retaining it after percussion or strain, are the causes of great perplexity to the mariner. Every gun in a ship is a magnet by induction, and the polarities as well as their intensities vary according to position. A ship leaning over in one direction will have all her guns within presenting a row of north poles on one side and south on the other; the needle deviates from the true meridian in accordance with these influences. If the ship leans over on the other side, which she can do by changing her tack, all these polarities are reversed or modified, so as to produce an altogether different influence on the compass. Instances are on record of ships having been lost by steering a wrong course from these causes.

Magnetism of Iron Ships.—Since masses of iron are magnetic by the earth's induction, it follows that an iron ship must be a great magnet, and she is therefore found to possess two kinds of magnetic polarity,—the one variable, and constantly changing with her positions in regard to the magnetic meridian; the other a sub-permanent magnetism, hammered as it were into her by the percussion of riveting, which fixes to a certain extent the magnetism due to her

position whilst being built. When an iron ship stands with her length in the direction of the magnetic meridian, her north half becomes a north pole, and the south half a south pole, the neutral centre being marked, not by a vertical section but by a transverse sectional plane at right angles to the magnetic dip.

When a ship lies east and west, this sectional plane will run through her in the direction of her length, but the angle which it forms with her vertical section is such that her upper portion and her south broadside possess south polarity, whilst the north broadside and the lower portion possess north polarity. Thus if a ship in the northern hemisphere lie with her head to the east, her deck and starboard broadside will be south, whilst her port broadside and bottom will be north, and *vice versa* when her head points to the west.

The vertical funnel undergoes no change by this change of position, the lower end being always of the same polarity as that of the hemisphere in which she happens to be, that is, north in the north hemisphere, and south in the south hemisphere.

The same relative changes in the magnetism of a ship take place in the southern hemisphere, but since the dip is in the opposite direction, the neutral transverse section will also be in the opposite direction, so that when a ship lies with her head to the east in the southern hemisphere, her starboard broadside and bottom will be south, whilst the deck and port broadside will be north; and when lying with her head to the south, the bow and stern will be respectively south and north. It is clear, then, that a new iron ship must be more or less under the influence of two magnetic polarities, the one constantly varying with her position, and the other fixed and derived from her position in building.

As a ship changes her position, these polarities will occasionally act in conjunction with, or in opposition to, each other, or the forces may also act at every conceivable angle, producing an endless variety of influences upon the compass. These errors are ascertained by swinging the ship, as it is termed, into various known positions, and from these observations tables of corrections are made out for the guidance of the mariner. Attempts have been made to counteract these influences by the application of fixed magnets, which are worse than useless, as they often double the error instead of correcting it.

The sub-permanent magnetism which a ship receives in the process of building often disappears by the strain occasioned by a storm, the effects of which are analogous to those of percussion, so that it is not unusual for a new ship to start on a voyage highly magnetized, and return neutral, or even with her sub-permanent polarities slightly reversed.

It is usual on board ship to place an additional compass high up in the mast, so as to be as far as possible removed from the variable influences of the hull; this serves as a sort of check, by which to compare the other compasses and discover changes in the magnetism of the ship.

The properties of a magnet are not at all affected by the presence or absence of air. The power of a magnet is greatly weakened by heating it, and a white heat entirely destroys it.

TOTAL FORCE.—HORIZONTAL AND VERTICAL INTENSITY.

The total magnetic force is the horizontal force *plus* the vertical force, acting in directions at right angles to each other.

The force which makes the declination needle oscillate is only a portion of the total magnetic force, and is smaller in proportion as the inclination is greater. Let line A C = M represent the total intensity, angle i the inclination, then the horizontal component A B is M cos i. Hence to express the inten-

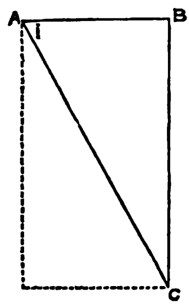


Fig. 12.

sities in two places by the declination needle we must adopt the following equation :—

$$\frac{M \cos i}{M' \cos i'} = \frac{N^2}{N'^2}$$

The horizontal intensity is found to vary annually. At Paris and London it is greatest about the vernal equinox, diminishes from that time to the summer solstice, and increases again during the following nine months. The variation does not exceed 18′.

Diurnal variations are also observed. In this country the north pole moves every day from east to west until one or two o'clock, then turns east, and regains its first position at about ten o'clock. The westerly declination is greatest during the hottest part of the day. This variation is between 5′ and 25′.

Necessary Apparatus used in Magnetism.

	s.	d.
Two pieces of magnetic iron ore	4	0
Two bar magnets, 12 in. × $1\frac{1}{2}$ × $\frac{1}{2}$	10	0
Horseshoe magnet	10	0
Magnetic needle on pivot	5	0
Dip needle	10	0
Soft iron bars, star shapes, &c.	2	0
Astatic needle	5	0
Electro-magnet	21	0
Bars of antimony, bismuth, and nickel	10	0

A person of any ingenuity may readily construct most of the apparatus mentioned, at a trifling cost. For instance, a dip needle may be made with a small cork, a sewing needle thrust through the cork transversely, and a long fine knitting or darning needle, magnetized and run through the cork longitudinally. Overturn two tumbler glasses of the same size, and balance the ends of the sewing-needles upon the tumblers, which must be placed east and west. The long needle will show the angle of dip. Again, an astatic needle is simply a couple of equally magnetized needles with their poles in reverse positions; the needles are fastened firmly to each other at a distance of about an inch. A long hair will serve to suspend them from any support.

The Department pays 50 per cent. of the cost of apparatus purchased from certain manufacturers. With his own half of the money a teacher of science may, on the whole, obtain a better set of apparatus without being hampered by regulations, and the goods will be his own.

ELECTRICITY.

Electricity is that branch of physics which treats of the laws of attraction and repulsion exhibited by bodies under certain circumstances.

Electricity is one of those subtle agents without weight or form, which appear diffused through all nature, existing in all substances, without affecting either their volume or temperature, or giving any indication of its presence when in a latent condition. When, however, it is liberated from this condition, it is capable of producing the most sudden and destructive effects, or of exciting powerful influences by long-continued action. Electricity may be excited or called into existence by mechanical, physical, or chemical action.

The Mechanical Sources of Electricity are friction, pressure, and a separation of the molecules or particles of a body. If a piece of loaf sugar be suddenly broken in a dark room, a feeble light is emitted, which is due to the development of electricity at the moment of separation of the particles.

The Physical Sources of Electricity are variations of temperature. Some minerals, on being heated or cooled, exhibit electrical phenomena.

The Chemical Sources of Electricity are the composition and decomposition of chemical compounds. Metals, such as zinc, copper, iron, and the like, when thrown into a solution of sulphuric acid and water, are attacked, and form compounds known as salts. During these changes considerable quantities of electricity may be developed. The most prominent and important causes of electricity are friction and chemical action.

Discovery of Electrical Properties.—More

600 B.C.

than two thousand years ago Thales knew that when amber was rubbed with wool it acquired the property of attracting light bodies, such as small pieces of paper, the barbs of a feather, and the like. The ancients explained this phenomenon by supposing that amber had the power of suction, and that light bodies were sucked towards it. As amber was a rather rare substance, and its origin not well understood, they said it was formed from the tears of a large Indian bird. Six centuries after the death of Thales, Pliny says that the friction of the fingers imparts life to yellow amber, which attracts straw, the same as the loadstone attracts iron. This was all the knowledge possessed of this subject until the end of the sixteenth century, when Gilbert called attention to the properties of amber, and showed that not only amber, but a great number of other substances, such as glass, resin, sulphur, and the like, acquired the same property as the amber by being rubbed with a woollen cloth or a catskin. This experiment is easily performed. Rub a stick of sealing-wax or glass with a woollen cloth; then present it to light shreds of gold-leaf, or fragments of paper, and they will be seen to approach and adhere to the glass or sealing-wax with which the experiment was made. It may be also observed that these rubbed bodies become luminous, and emit sparks and display a number of other properties known as electrical phenomena. During the present century a number of new facts have been discovered, which now form a rather extensive range of science.

We have just mentioned that a rod of smooth glass or a stick of sealing-wax, rubbed with a piece of woollen cloth or dry flannel, will be found to have acquired a new physical property, viz., that of instantly

attracting small bodies. Some of these will adhere to the rod or stick; others will fall back on the table; and others be thrown off as if they were repelled. The property which has been communicated by friction is called electricity; the body which acquires this property is called an electric; and the attraction of the bodies is called electrical attraction. The electric, or body rubbed, is said to be excited or electrified, and the body by which it is rubbed is called the rubber.

These simple phenomena may be shown by the action of resinous bodies on a dry pith ball, or piece of cork about the size of a small pea. Let the ball, B, (*Fig.* 13), be suspended by a fibre of raw silk. Having rubbed a glass rod with a piece of dry silk, present it to the ball, and the ball will instantly be attracted to the rod and adhere to it. After they have been in contact for a second or two, withdraw the glass rod without touching the ball with the fingers. If the excited glass rod be again excited, and presented a second time to the ball, it will recede from it, or be repelled. If, after touching the ball with the finger, so as to deprive it of its electricity, the experiment be repeated with a stick of sealing-wax instead of glass, the very same phenomena will occur; the ball will be first attracted and then repelled. From these experiments we observe that both the glass and sealing-wax attract the ball, B, before they have communicated to it any of their electricity,

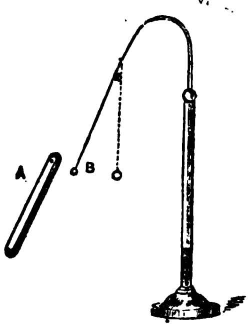


Fig. 13.

and that both these electrics repel the ball after each of them has communicated a portion of its electricity to the ball. Let us now see what takes places when the excited sealing-wax is presented to the ball after the ball has received electricity from the glass rod, and *vice versa*. Excite the glass rod and present it to the ball, and after it has been a second or two in contact, remove it. The ball has now received electricity from the glass rod. Excite the sealing-wax and present it to the ball. The ball will not be repelled, but attracted. Reverse the experiment by first presenting the excited wax to the ball, and then the glass, and it will be found that the glass attracts the ball.

Excited glass repels a ball electrified by excited glass. Excited wax repels a ball electrified by excited wax. Excited glass attracts a ball electrified by excited wax. Excited wax attracts a ball electrified by excited glass. From this it appears that there are two opposite kinds of electricity, viz., that produced by excited glass, and that produced by excited wax. To that obtained upon glass the name vitreous was applied originally, whilst the one that was excited on the wax or resin was termed resinous. The names are not now used, for the relative nature of the substances determines the kind of electricity: for example, rub glass with silk, and positive electricity is developed; now rub with cat's fur, and negative will be obtained. The terms + and –, or positive and negative, are now commonly used. They are undoubtedly derived from Franklin's one fluid theory.

After the pith ball has been electrified, either with an excited glass rod or sealing-wax, we touch it with a rod of glass. The property of its being subsequently attracted or repelled by an excited rod of glass or

wax will not be altered; but if we touch it with a rod of metal, it will lose the electricity which it received from the glass rod or wax, and return to the condition it was in when they were first applied to it. The glass rod and the rod of metal possess different properties. The metal carries off the electricity from the ball, and is a conductor, and the glass a non-conductor.

The Hypothesis of Two Electrical Fluids.—This theory supposes all bodies to possess a compound neutral fluid, which when decomposed by friction or otherwise gives electrical action. The earth is regarded as the great reservoir of this fluid, which has of itself no obvious active properties. Hence bodies which simply contain it are said to be neutral. If by friction or chemical action, or other causes, the neutral fluid is decomposed, and the two fluids separate, electrical phenomena are at once developed.

Like electricities repel, unlike attract.

If the quantities of dissimilar fluids be exactly equal, they neutralize each other; that is, they bring about a state of electrical indifference; or a state identical with that of the earth.

The Theory of Franklin proposes one fluid only, and explains the variation in electrical phenomena by the supposition that when bodies are not neutral they are charged with a + quantity or − quantity of the same fluid. Instead of + and − positive and negative are often used. All the phenomena can be explained by this theory, and when mention is made of two fluids, it is simply because the hypothesis is more easily applied and generally used.

Another theory, that of induction, is much in favour at the present time. It will be treated upon in a later portion of this work. The reader is here cautioned against confusing his mind with the different

theories advanced. Bearing in mind the meaning of the word theory, he will find that in subsequent pages explanations of apparatus are given in the language of two or more theories. These must not be looked upon as contradictions. They are intended to enable the student to explain electrical phenomena and the language of any one of the three theories if called upon to do so.

Conductors, or conducting bodies, are those which permit the electricity to pass readily along them.

Insulators, or non-conducting bodies, are those which do not permit electricity to pass readily along them. Insulators were formerly called electrics, and conductors non-electrics. In the latter case by friction a charge could not be developed. It was overlooked that the non-electric required insulating, when it would have been found that the charge was obtained as in the case of insulators. The terms are now obsolete, and are given here as historical marks to show the progress of the science.

Conductors or Anelectrics.	Insulators or Dielectrics.
The metals.	Shellac.
Charcoal.	Amber.
Plumbago.	Resins.
Strong acids.	Gutta-percha.
Soot and lamp-black.	Sulphur.
Metallic ores and oxides.	Wax.
Dilute acids.	Asphaltum.
Saline solutions.	Glass & all vitreous
Animal fluids.	Raw silk. [bodies.
Sea-water.	Bleached silk.
Rain-water.	Dyed silk.
Ice and snow above o° F.	Wool, hair, feathers.
Living vegetables and animals.	Dry gases. [ther.
Flame.	Dry paper and lea-

Smoke.
Vapour.
Salts.
Rarefied air.
Dry earths.
Minerals.

Baked wood.
Porcelain.
Marble.
Camphor.
Caoutchouc.
Lycopodium.
Dry chalk and lime.
Phosphorus.
Ice below 0° F.
Oils.

In each table the substances are arranged according to their relative powers, commencing with the best conductor at the top of the first table, and the best insulator at the top of the second.

The following table, taken from De la Rive, gives a list of substances, each of which becomes positively electrified when rubbed with either of those which follow it; and negatively when rubbed with either of those which precede it.

The skin of a cat.
Diamond.
Flannel.
Ivory.
Rock crystal.
Wool.
Glass.
Cotton.
Linen.
White silk.
Gutta-percha.
Collodion.
Gun-cotton.
The dry hand.
Wood.
Sealing-wax.
Amber.
Sulphur.
Caoutchouc.
Gun-cotton.

Methods of Electrifying Bodies.—Non-conducting bodies are only electrified by friction, but conductors may be electrified either by friction, by contact, or by induction. To electrify a metal it must be insulated—that is, it must be supported by a non-conducting body,—and it must be rubbed by an

insulator. This may be accomplished by mounting the metal on a stand of glass and rubbing it with a non-conductor (a piece of dry silk). Were the metal not insulated, the electricity would flow off to the earth as fast as generated; and if the rubbing body were not a non-conductor, the electricity would flow off through the arms and legs of the experimenter.

The method of electrifying a body by conduction depends upon the property of conductibility. If a conductor is brought into contact with an electrified body, a portion of the electricity of the latter flows upon the former body. If the two electrics are alike, the electricity will be equally distributed over both. If they differ in size or shape, the electricity will not be equally distributed over both.

The method of electrifying bodies by induction is similar to that of magnetizing bodies by induction.

When a body charged with one kind of electricity is brought into close proximity with other bodies, without actual contact, it induces an opposite electrical condition. To this, as in the science of magnetism the term induction is applied.

Electrical Induction.—This effect arises from the general law of electrical attraction and repulsion. A body in its neuter condition is supposed to contain equal quantities of negative and positive electricity, and when this is the case the body is in a state of equilibrium; but when a body charged with electricity is brought into proximity with a neutral body, disturbance immediately takes place. The electrified body, by its attractive and repulsive influence, separates the two electricities of the neutral body; repelling the one like itself, and attracting the opposite. Thus if a body positively electrified be brought near a neutral body, the positive electricity of the neutral

body, will be repelled or driven to the most remote part of its surface, but the negative electricity will be attracted to the point nearest to the disturbing body. Between these extreme points we can imagine a point which is neutral, separating, as it were, the two opposite fluids. Let C A D (*Fig.* 14) be a metallic cylinder placed on an insulating support, with two pith balls suspended at the end, D. If now an elec-

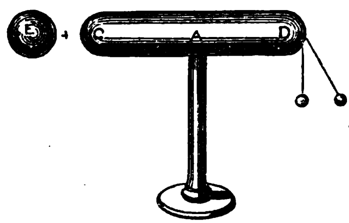


Fig. 14.

trified body, such as an electrophorus, be brought near to the end, C, of the cylinder, the balls at the other extremity will instantly diverge, showing the presence of free electricity. This does not arise from any transfer of the electricity from the electrified body, E to C, for upon withdrawing the electrified body, E, the balls will fall together and appear unelectrified as before; but the electricity in E decomposes, by its proximity, the two electricities in the cylinder; atracting the kind opposite to itself to the one end, and repelling the same kind to the other end. The middle point, A, will be neutral, and will neither exhibit positive nor negative electricity. If three cylinders (*Fig.* 15.) be placed in a row touching one another, and a positively electrified body, E, be brought into proximity to one extremity, the electri-

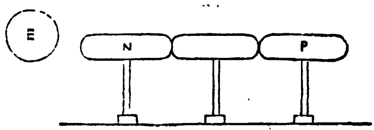


Fig. 15.

cities of the cylinders will be decomposed, the negative accumulating in N and the positive repelled to P. If whilst in this condition the cylinder, P, be first removed, then the electrified body, the separate electricities will not be able to unite, as in the former illustration, but N will remain negatively and P positively electrified. From these experiments we can understand why an electrified surface attracts a neutral or unelectrified body, such as a pith ball. It is not that the electricity causes attractions between excited and unexcited bodies, the same as between bodies in opposite electrical states, but the electricity of the pith ball is decomposed by the electrified body; and of the two products of the decomposition, the one which is unlike the electrified body is nearer to it than the one which is like. Accordingly, attraction prevails over repulsion. When the two touch they become alike in their stages, and repel each other.

In describing magnetic induction it was shown that the greater the length of the iron bar induced upon by a magnet, the greater was the attractive effect.

The influence of length upon electrical inductive susceptibility is beautifully shown by the following arrangement. Fasten a tall slender rod glass, vulcanite, or other non-conducting substance, A, *Fig.* 16), into a wooden foot, B, and fix on the top of it a light horizontal bar of wood or metal, C, about a foot long. From one end of this cross-bar suspend by a silk

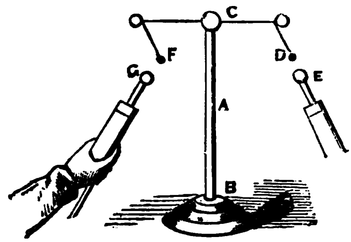


Fig. 16.

string a pith ball, D. Bring near to this ball an excited glass tube surmounted by a wire and brass ball, E.

The pith ball, D, will be attracted; notice the distance at which the attraction takes place; this will be greater in proportion to the distance to which the two electrical polarities induced in the ball can separate from each other; this of course is only the diameter of the ball, so that whilst the electricity of the opposite or attractive kind is drawn towards the side nearest the excited tube, the electricity of the same name is so close at hand as to control by its repelling quality the attraction thus produced.

Substitute for the silk string of the pith ball, D, one of thread or cotton, and present the excited tube again; the attraction will now take place at a considerably greater distance, since the electricity of the same name can now retreat through the thread to the further end of the cross arm, C, leaving the opposite electricity induced in the pith ball, D, free to be attracted by E.

Now hang a second pith ball, F, by a thread from the other end of the cross arm, C. Present the excited tube, E, to the first ball, D, until attraction ensues. The attracting distance will be found to have still further increased. Whilst D is being attracted

by E, in virtue of its oppositely induced electrical state, bring a second and similarly excited glass tube, G, gradually near to the ball, F. Repulsion and not attraction will here be found to take place, the electricity of the ball, F, being similar to that of the glass tubes. As G is brought nearer to F, it begins to act upon it in virtue of its more exalted electrical condition, and drives back again a portion of the electricity which had retreated into it from D, the effect of which is to diminish the attraction between D and E.

If G be brought so near to F as to be capable of driving back all the electricity to D, matters will suddenly be reversed, and attraction will take place between G and F, and repulsion instead of attraction between D and E. These effects may again be reversed at pleasure by bringing the tube, E, intended to produce attraction near enough to its ball, D, to overcome the induction of the tube at the other end.

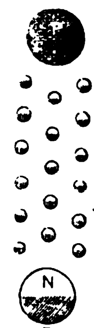


Fig. 17.

Theory of Induction. — Faraday conceives electrical induction to depend on the physical action between the contiguous molecules, which takes place at a distance by operating through the intervening particles of non-conducting matter. In these intermediate particles a separation of the opposite electricities takes place, and they become decomposed in an alternate series or succession of positive and negative points or poles. This he terms a polarization of the particles; and in this way the force is transmitted to a distance. Thus, in *Fig.* 17, P represents a body positively charged with electricity, and the particles

between are air or other non-conducting matter. Then the action of P is transmitted to a distant body, N, by the separation and electrical polarization of the particles indicated by the black and white hemispheres. If the particles can retain this state, insulation is the result; but if the forces communicate, or discharge one into the other, then we have an equalization of the respective opposite electricities throughout the whole series, including P and N. He further assumes that all particles of matter are more or less conductors; that in their quiescent state they are not arranged in a polarized form, but become so by the influence of contiguous and charged particles: they then assume a forced state, and tend to return by a constantly increasing tension to their original normal condition. Contiguous particles can communicate their forces more or less readily one to the other: when less readily the polarized state rises higher and insulation is the result; when more readily conduction is the result. Insulation of an ordinary kind is the action of a charged body upon insulating matter, or matter the particles of which communicate the electrical forces to each other in an extremely minute degree, the charged body producing in it an equal amount of the opposite force, and this it does by polarizing the particles.

An Electroscope is an instrument employed to indicate free electricity. The most simple form of electroscope is the electrical pendulum (*Fig.* 13, p. 30), which consists of a light pith ball suspended by a fine silk thread. The thread is fastened to the upper end of a bent glass rod. To ascertain if a body, A, is electrified, it is presented to the pith ball. If it be electrified, the pith ball, B, will be attracted; if not, it will remain in its vertical position.

There is another form of pith ball *electroscope*, (*Fig.* 18), which consists of two balls suspended by conducting threads in a glass jar, and connected with a brass cap. On touching the brass cap, B, with the electrified body, C, the two balls, being similarly electrified, will repel each other. A more delicate *electroscope* consists of two slips of golf-leaf instead of the pith balls. If an excited substance, C, be brought near the brass cap, B, the two leaves will instantly diverge. When no electricity is present the two gold leaves hang together. The gold-leaf electrometer may be used not only as an electroscope or detector of the presence of electricity, but it will also help us to conclude whether we have obtained a positive or negative charge on any substance with which we may be experimenting. Place a negatively electrified body over the instrument; the knob will be charged with positive and the leaves with negative by induction. Touch the knob, and the positive charge will be neutralized, leaving the instrument charged with negative. If now it be required to find out the kind of electricity with which a body is charged, place the substance

Fig. 18.

in the neighbourhood of the knob. If the leaves fall completely together, it is because the charge presented was positive, and has neutralized the former negative charge. The approach of a neutral body can only cause a partial collapse of the leaves. The

leaves would repel still more if negative electricity were brought near the instrument. A small condenser is sometimes attached to this electroscope to increase its delicacy. A brass plate about four inches in diameter is the cover of the glass jar, and another brass plate of the same size, with an insulating handle, is placed on the top. The under surface of the latter is coated with copal varnish to prevent metallic contact between the two plates. Enough will be said on the electrophorus and condenser, to explain the action of this instrument. Traces of electricity so feeble as to give no sign with the gold leaves alone may readily be detected by this addition. ELECTROMETERS must be insulated and dry, so that the electricity communicated to the balls or leaves may not pass away.* Another form, called the QUADRANT ELECTROMETER (*Fig.* 19), consists of a quadrant or semicircle of white varnished paper, or ivory, B, fixed on a vertical rod, which may be attached to the conductor of an electrical machine. From the centre of the semicircle a light pith ball is suspended, and the number of degrees through which the ball, A, is attracted or repelled by any body brought into proximity with it indicates in a degree the amount of electricity present. No very accurate results can be obtained from this apparatus; and for more careful investigations Coulomb's TORSION BALANCE is usually employed (*Fig.* 20). A

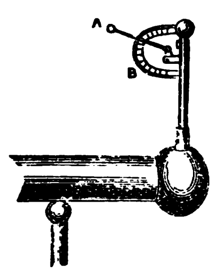


Fig. 19.

* Even the air they contain must be carefully dried; this may be done by placing a little $CaCl_2$ under the cover. Chloride of calcium rapidly absorbs moisture.

needle or stick of shellac, having at one end a small gilded pith ball, *o*, is suspended by a fibre of silk in a glass tube, which terminates in a cylindrical glass vessel about nine inches in diameter. The needle is so balanced that it is free to move horizontally in any direction about the point of suspension. Within the glass vessel a graduated circle, *r*, is placed, which measures the angle through which the needle is deflected. In the cover of the vessel, at *d*, an aperture is made through which the electrified body is introduced. The centre of the ball, *o*, corresponds to the zero of the scale. In every experiment the charge must be communicated to the ball connected with *d* which is done by removing it from the apparatus and bringing it in contact with an electrified body, and then placing it in its proper position. The moveable ball, *o*,

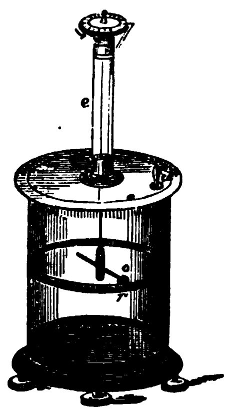


Fig. 20.

at once is attracted by the electrified fixed one; contact ensues, resulting in the establishment of identical electric condition between the two. Repulsion therefore follows, and the amount of the repulsion, and therefore the amount of charge, is measured by the distance apart at which the balls remain in equilibrium, that is, by the torsion of the thread. By turning the upper cap in a direction opposite to that of the moving ball, the latter can be brought to any required place; and the amount of turning required to effect this measures

the charge. The instrument is adjusted by levelling screws, and at the upper end of the tube, *e*, a circular piece of ivory, *a*, is placed, on which a scale is marked. A small index is attached to the fibre of silk, which moves round the centre of suspension and also indicates the degrees. By means of this balance Coulomb established the following laws :—

1. *The repulsions or attractions between two electrified bodies are in the inverse ratio of the squares of their distance.*

2. *Distance being the same, the attractive or repulsive force is directly as the product of the charges.*

In experimenting, arrange the index at zero of the small ivory scale at the top of the tube. The ball attached to *d* is at zero of the graduated scale below, and the tube, *e*, is turned until ball, *o*, is also at zero, therefore the two balls are touching. Now remove *d*, charge the ball and replace it; ball, *o*, will be repelled to a certain distance, and the force necessary to overcome this resistance and to bring the ball back again is the means employed to estimate the power of the repulsion. In a special experiment Coulomb found that *o* was repelled through 36°. In order to bring the angle to 18° it was necessary to twist the index, and with the supporting thread through 126°.

Torsion remaining . .	18°
,, imparted . . .	126°
Total . . .	144°

Again move the index and thread so as to reduce the angle to 9°; 567° of torsion are necessary.

Torsion remaining . .	9°
,, imparted . . .	567°
Total . . .	576°

Result—

At 36°, 18°, 9°
or 1, $\frac{1}{2}$, $\frac{1}{4}$ the distance.
Torsion is 36_0 144°, 576°
or 1, 4, 16 „

We then see that for a distance half as great, the angle of torsion is four times as much, and that for a distance of one-fourth the torsion is sixteen times as great. (*See Exercises.*)

The experiments by which the law of attraction is demonstrated are much the same. The two balls are charged with opposite electricities, and sufficient twist is imparted to fix one ball at a certain distance from the other; then calculations are made from the torsion necessary to force *o* still further away, as in the preceding experiment.*

The Balance Electrometer, employed by Sir W. S. Harris in his investigations on the laws of electrical accumulations, is a simple and useful instrument. It consists of a delicate scale beam suspended from a brass support. A scale pan hangs from one end, and a gilded disc of wood, about $1\frac{1}{2}$ inches diameter, replaces the scale pan at the other end. The scale pan rests on a suitable support, so as to keep the beam horizontal. Beneath the gilded disc is placed a corresponding metallic disc parallel to it, and insulated on a glass rod, which slides up and down in a socket, so as to

* There are certain limitations to the law of inverse squares to which we must here allude. The form of the charged body modifies the law, since it is only strictly true with regard to forces acting from points, and of course from spheres, the entire charge of which will act as from a common centre. Again, when two charged bodies are brought within each other's field of attraction the distribution of electricity is not the same, for each body will act inductively on the other, and this of course would materially affect an experiment conducted with them.

permit the two discs to be placed at any required distance from each other up to a range of six inches. The insulated disc being connected with the interior of a Leyden jar or other electrified conductor, attracts the disc suspended from the scale beam, the force of the attraction being estimated by the number of grain-weights necessary in the other scale pan to balance the attractive force.

The Electrophorus (*Fig.* 21) is a most valuable instrument, and its invention is due to the ingenuity of Volta. By this machine we may obtain considerable quantities of electricity by induction. It consists of a circular cake of resin or shellac, A, laid upon a metallic plate.* On this cake is placed a metallic cover, C, somewhat less in diameter than the cake, and furnished with a glass insulating handle, B. When the cake of resin has been negatively electrified by beating or rubbing vigorously with dry silk, place upon it the metallic cover. The negative electricity of the resin, acting by induction on the neutral condition of the cover, separates the two electricities, attracting the positive electricity to the under surface, and repelling the negative to the upper surface. Touch the upper side of the upper plate with the finger, the negative will be neutralized by positive from the ground, whilst the positive charge will be bound until the upper plate is removed by the insulating handle, when it becomes free, and may be imparted to any insulated conductor adapted to receive it. The process may be repeated

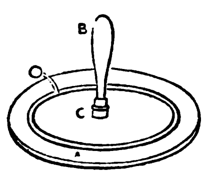


Fig. 21.

* A sheet of tinfoil attached to the under side will act very well.

indefinitely, as the resinous cake loses none of its electricity, but simply acts by induction, and thus the insulated cover may be charged. This resinous or negative electricity which has been developed on the surface remains, because it is bound by the opposite electricity on the under side. We must take care to let the metal disc remain on the resin, the presence of which prevents the loss of electricity that would result from contact with the atmosphere.

The apparatus is extremely useful to demonstrate electrical induction, and at the risk of repetition, a brief account of the entire action on the inductive theory is introduced.

Naming the plates in order upwards as *a*, *b*, *c*, plate *a* is put in connection with the ground by some conductor, *e. g.*, the body of the operator; *b* is then placed upon *a*, and its upper surface is rubbed with a rubber of dry silk. The two plates are now charged, *a* with positive electricity, *b* with negative, each binding the other in its position. Now place *c* on the top of *b*. Its neutral state is upset, positive electricity arranging itself on its under side, and negative on the upper. Touch the upper side, and the negative will be neutralized by positive from the earth through the body. Remove plate *c* by the insulating handle, and a spark may be obtained from the discharging ball, consisting of the positive electricity which was before bound by contiguity to the negative of plate *b*.

If we raise *c* without previously touching it with the finger, we find it either neutral, or charged by contact with the under plate, from which it has received a small quantity of free electricity. Any good non-conductor may supply the place of a resinous plate; a piece of sheet gutta-percha or vulcanite, from $\frac{1}{8}$ to $\frac{1}{4}$

of an inch thick, give much better effects than the resin.

A hot pane of glass may be employed, and the electricity is then of the opposite character, glass yielding positive electricity by the same process which develops negative from gutta-percha, &c. If two of these instruments be excited at the same time, the one of glass and the other of gutta-percha, and their electrified covers be brought near to each other, sparks of two or three inches in length will be obtained from the attraction of the two electricities for each other.

An extemporaneous electrophorus can be made with a half-sheet of writing-paper, letter size, a small metal waiter, and a wine-glass, with which the following experiments can be shown:—

1st. Make all three articles hot by the fire, place the wine-glass inverted on a dry table, and put the metal waiter upon its foot; this constitutes an insulated conductor.

2ndly. Lay the warm sheet of paper upon the table, rub its surface over with a piece of india-rubber; this will excite the paper like an electrophorus plate, and it will be found to adhere to the table.

3rdly. Lift the paper by the two opposite corners, and drop it upon the insulated waiter. On presenting the knuckle at once to the edge of this latter a bright spark may be obtained.

4thly. Lift the paper again carefully by the corners, taking care not to touch the waiter, and a second spark of electricity of the opposite character will be observed. Drop the paper again upon the waiter, and it would give a third spark similar to the first. This operation may be repeated several times with expert manipulation.

If when the paper is first lifted from the table it be placed against the wall of the room it will adhere to it until it has attracted moisture enough to render it a conductor. It will return to a neutral state by attracting the opposite electricity from the ground.

Similar experiments may also be performed, and the action of the electrophorus illustrated, by means of a sheet of stout brown paper placed upon a tea-tray. Develop the electricity by friction on the paper with india-rubber. The general conclusion to be drawn here is, that two conducting plates separated by an insulating plate are all that are required, and any substances fulfilling these conditions will easily be arranged to give the results here noted down.

An Electrical Machine is an apparatus by which electricity is developed and accumulated in a convenient manner for purposes of experiment. All electrical machines consist of three principal parts,—the rubber; the body on whose service the electric fluid is evolved; and one or more insulated conductors, upon which the electricity is confined. There are two kinds of machines—the plate machine and cylinder machine. They derive their names from the shape of the glass employed. The plate machine (*Fig.* 22) consists of a large circular plate of glass, T, mounted on a brass axis, and supported by wooden pillars, fixed securely into the base, so that the plate can be turned by the handle, W. At the top and bottom of the glass, and fixed so as to press easily but uniformly on the plate, are rubbers, *r r r r*, and flaps of oiled silk, *s s*. When the machine is put in motion, these flaps of silk are drawn tightly against the glass, and thus the electricity produced by the friction of the rubbers is kept on the glass until the points of the conductor are reached. These points, *p p*, collect the

electricity from the glass as it revolves, and convey it to the prime conductor, C, which is insulated by depending on glass supports. The explanation of the action here given is on the two-fluid theory, which ignores the more modern theory of induction. In a later part of the same article the action of an electrical machine is explained in the latter theory. The rubber of an electrical machine consists of a cushion stuffed with hair, and covered with soft leather, silk,

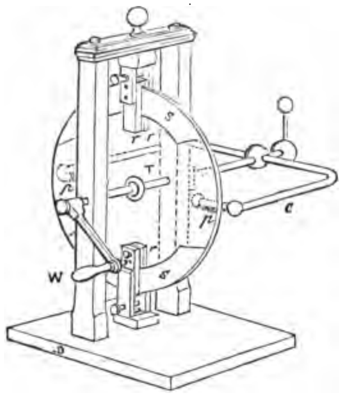


Fig. 22.

or some substance which generates electricity by friction. The efficacy of the machine is greatly increased by covering the cushion with an amalgam made of two parts, by weight, of zinc, one of tin, and six of mercury, mixed with a sufficient quantity of lard to make it of the consistency of paste; a thin coating is spread on the cushions, and the machine carefully dusted and warmed. The lower rubber to be only on one side of the support. (*See Fig. 22a.*)

The Cylinder Electrical Machine was invented by Nairne. It consists of a glass cylinder, blown with a neck at either end; upon these necks are cemented wooden caps, furnished with axles, upon one of which the handle is fastened. The cylinder is then mounted so as to turn between two uprights fixed in a base of wood. The rubber is attached to a strong glass leg, the lower end of which is fastened into a wooden foot, sliding in a groove on the base of the instrument, so as to increase or diminish pressure. A brass or japanned tin conductor is fixed against the back of this rubber, in order to augment its electrical effects. The prime conductor is placed in front of the machine, diametrically opposite to the rubber, and is supported on a glass pillar. There is a row of points on the side nearest the cylinder. The rubber is furnished with a flap of silk, which extends over the top of the cylinder to within half an inch of the points of the conductor. By this arrangement either the rubber or prime conductor can be insulated, so as to render either positive or negative electricity available for experiment,—a great desideratum.

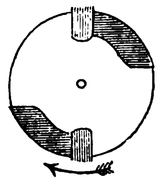


Fig. 22*a*.

These machines are extremely powerful in proportion to the surface rubbed, and are made with cylinders from 4 to 14 or 16 inches diameter. As a rule, cylinder machines will give zigzag sparks equal in length to rather more than three-fourths the diameter of the cylinder, and having only one rubber they are more convenient to manage. Where very greatpower, however, is required, the plate machine of course has the preference. A 7 or 8-inch cylinder machine will be found a convenient size for class illustration.

Electricity developed by a machine is essentially

the same as that developed by rubbing a glass rod with a piece of silk. When the glass plate is turned round by the handle, the friction between the glass and the rubber excites the electricity, positive being developed on the glass, and negative upon the rubber. The points of the prime conductor are presented to the revolving glass plate, and the positive electricity is immediately neutralized by the negative from the prime conductor which it has attracted to it. The positive charge remains, and sparks may be obtained. By means of this same inductive theory we have still to explain why sparks are obtained, and also what becomes of the negative charge of the rubbers on each occasion when the positive of the plate is neutralized. In the former case, let us suppose that a rod of metal is presented to the knob of the charged conductor; a spark will immediately pass. This spark is caused at the instant of neutralization of the positive of the conductor by negative attracted from the rod, which again will become neutral instantly by negative attracted from the earth, if connected with it by a conductor.

The negative of the rudder attracts, by means of the connecting chain, which hangs down to the ground or is connected with gas-pipes, &c., positive from the earth, and of course also becomes neutral. Thus the whole machine may be looked upon as being polarized with a polarizing power acting in one direction, and the chain to the ground is necessary to neutralize the negative of the rubbers, which otherwise will bind and neutralize the positive of the plate, preventing a charge of any material strength.

The chain must always be attached to the rubber when it is desired to develop positive electricity, and to the prime conductor when it is desired to develop negative electricity. According to the single-fluid

theory the development of electricity is as follows :— The friction of the glass and silk, by disturbing the electrical equilibrium, deprives the rubber of its natural quantity of electricity, and it is therefore left in a negative state, unless a fresh portion be drawn from the earth to supply its place. The surplus quantity is collected on the prime conductor, which thereby becomes charged with positive electricity.

Other arrangements have been devised for the production and accumulation of electricity. High pressure steam escaping from a steam boiler carries with it minute particles of water, and the friction of these against the surface of the jet from which the steam issues produces electricity in great abundance. A machine of this sort at the "Polytechnic" produced flashes of electricity from the prime conductor more than two feet in length

The Leyden Jar (*Fig.* 23), as usually constituted, consists of a glass jar, having a wide mouth, and

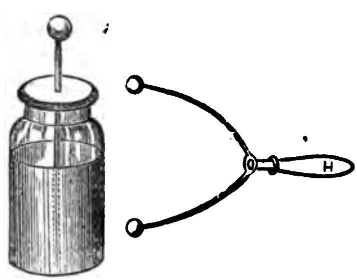


Fig. 23.

coated externally and internally, to within three inches of the top, with tinfoil. A wooden cover of well-dried mahogany, varnished, is fitted into the mouth of the

jar, through which a stout brass wire passes, having a few inches of chain at the lower end, so as to be in contact with the inside coating. The top of the brass wire is terminated in a knob about three inches from the cover. The Leyden jar is charged by holding the outer tinned part in the hand and bringing the knob in contact with the prime conductor of the electrical machine. Immediately the whole is polarized according to the inductive theory, *i.e.*, the positive of the conductor withdraws the negative of the internal coating or armature, itself becoming neutral, and the interior of the Leyden jar positive. This acts on the exterior coating, retaining or binding the negative, whilst the positive is driven off by means of the ground connection to the earth. After the jar has been charged, if it be held in one hand whilst the other is brought into contact with the knob, a shock is felt through the body, and the jar returns to its neutral state. When the jar has to be discharged without a shock, a discharger is used, which consists of two brass knobs, insulated by a glass handle, H. One knob is brought into contact with the outer coating of the jar, and the other is then brought into contact with the metallic kuob of the jar. In this case a spark is emitted, and the jar returns to its neutral condition. To charge the jar with negative electricity it is only necessary to reverse the preceding arrangement. Connect the interior with the ground, and the exterior coating with the machine.

Discovery of the Leyden Jar.—Musschenbroeck's name is connected with the discovery of this important instrument. More probably Cunœus, of Leyden, made the discovery in 1746. Musschenbroeck's experiment was thus conducted :—He held in his hand a flask full of water, into which passed

a wire from the prime-conductor of an electrical machine. He then found that on touching the prime conductor he received a violent shock; so terrible was this shock that he declared he would not receive another for the crown of France. It is clear that in this case the water was the inner armature and the hand the outer coating: of course, the prime conductor and wire with the other arm completed the circuit.

An Electrical Condenser is an apparatus employed for accumulating electricity. The condenser of Epinus (*Fig.* 24) is composed of two metallic plates, C and B, standing on supports of glass, with an intervening plate of glass, A, somewhat larger than the metallic plates. These plates are so mounted on a stand as to be made to approach or recede from the plate, A, by sliding along a groove. When the condenser is used, the plates, C and B, are moved up to touch the plate, A. The plate, B, communicates with the prime conductor of an electrical machine, and the plate, C, with the earth. The electrical machine is put in motion, which charges the plate, B, with positive electricity. Were it not for the plate, C, the quantity of electricity on each unit of surface of B would be the same as on a unit of surface of the prime conductor, but the presence of the plate, C, modifies the result. The plate, B, acts by induction on C, and drives its positive electricity to the earth, retaining its negative electricity by the force of attraction. The negative electricity of C now reacts on B, partially neutralizing the effect of its positive electricity. The electricity of B, being par-

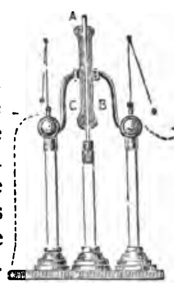


Fig. 24.

tially neutralized, no longer holds that of the prime conductor in equilibrium, and an additional quantity of the positive fluid flows into it, which acting as before, draws into C from the earth an additional quantity of the negative fluid, and so on. In this way there is gradually accumulated upon the surfaces of B and C large quantities of the positive and negative fluids. When the apparatus is fully charged we disconnect C with the earth and B with the prime conductor. In this condition the two electricities show no effect, but simply hold each other in equilibrium. There is, however, in consequence of the intervening glass plate, an excess of electricity in B, as shown by the electrometer placed in connection with it; but a similar electrometer placed in connection with C gives no such indication. If now the plates are separated, both electrometers will diverge, as they should do, because the two electricities no longer hold each other in equilibrium. In this condition the electricity of the two plates may be tested and shown to be opposite. If a rod of glass be rubbed with silk and brought near the electrometer upon B, it will be repelled, which indicates positive electricity; if it be brought near the electrometer on C it will be attracted, showing negative electricity.

The condenser may be discharged, or brought back to its neutral condition, in two ways—first, by successive contacts, in which the discharge takes place slowly, or by connecting the plates, B and C, by a conductor, in which case the discharge is instantaneous. If the plate, C, is touched no electricity is drawn off, because all that it contains is held in equilibrium by the plate, B. If, however, the plate, B, is touched, all its free electricity—that is, all which is not neutralized —is drawn off. After this a certain unneutralized

portion of electricity will exist on C, which will be indicated by the electrometer. By continuing to touch the plates alternately the whole charge may be drawn off in small quantities. To obtain an instantaneous discharge we might touch one plate with one hand, and the other with the other hand, when the two fluids would flow through the body and neutralize each other. This produces a shock, and to avoid this we make use of a discharger.

Two circumstances limit the amount of electricity that may be accumulated in a condenser. First, the unbalanced electricity in the plate, B, goes on augmenting with the charge, until at last its tension equals that of the prime conductor, after which no more can flow into the condenser from the machine. Secondly, the two electricities on the plates, C and B, tend to unite, with an energy which goes on increasing with the accumulation of electricity on the plates, and may become so great as to break through the glass, and thus cause a union of the two fluids, or discharge itself from one side to the other over the uncoated interval of glass, which is called the spontaneous discharge.

It will be well for the reader here to notice that the condenser is simply another form of the Leyden jar, of which again the electrophorus is an example. In both cases it is only necessary to imagine the jar to be flattened out into the form of plates, and on consideration the construction and theoretical explanation of their action will be found to be the same in all important particulars.

Cascade Arrangement.—A number of Leyden jars are placed on insulating supports, as in *Fig.* 25. The charged prime conductor is brought near to the knob of the first jar; the result is that this jar is

charged inductively. Its negative electricity is removed, and positive collects in the interior. The exterior armature is charged with negative, and insomuch as the exterior of jar No. 1, and the interior of jar No. 2 are one conducting surface, as the negative has been attracted to the exterior of No. 1, the positive is repelled to the interior of No. 2, which

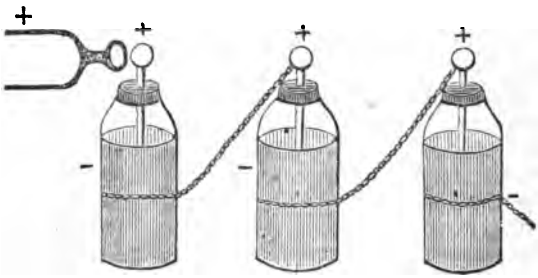


Fig. 25.

again reacts on jar No. 3, as the first jar acted upon No. 2, and so on until the whole series is charged, the last jar having an earth connection, so that the repelled positive may pass to the earth.

The discharge by cascade may then be obtained by connecting the exterior coating of the last one with the interior armature of the first, or each jar may be discharged separately. In this way the quantity of electricity necessary for charging one jar may be employed to charge an almost unlimited number of jars, and of course the quantity of electricity obtained is proportionably larger according to the number of jars employed.

Harris's Unit Jar.—This instrument is very useful for measuring quantities of electricity. It

consists of a small Leyden jar about 4 in. long, and ¾ in. in diameter, coated to about one inch from the end, so as to expose about six inches of metallic surface. It is fixed horizontally on an insulator, B, the charged prime conductor of the electrical machine is

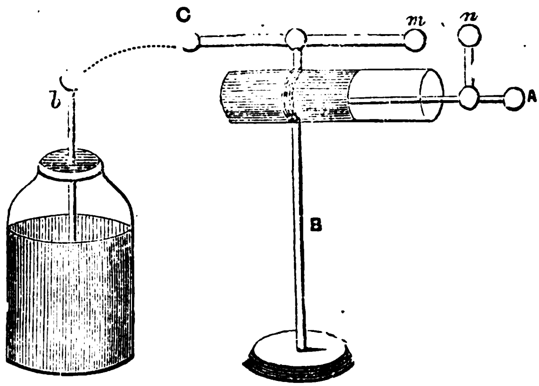


Fig. 26.

brought into connection with A, and the outer coating is connected with the jar which acts as receiver, by the rod, *c b*. When the small jar is charged to a certain fixed amount, depending on the distance between *m* and *n*, a discharge takes place; this may be taken as a unit by which to discharge one jar with three times the quantity of another, and so on.

Some little difficulty may here present itself to the student. He may ask, Why does the second jar become charged at all? and if charged, why does it not discharge at the same time as the smaller jar? A little consideration will readily simplify the matter. The second jar is charged with positive by the inductive

action of the outer coating of the small jar, and its charge is not lost at the time the small discharge occurs, because the interior positive is bound to its place by the exterior negative of the second jar or battery, which should have a ground connection.

An electrical battery consists of a series of Leyden jars, whose external and internal coatings are respectively connected with each other. The jars are usually placed in a wooden box, lined on the bottom with tinfoil, which connects the external coatings, which are also connected with two brass handles on the sides of the box. The internal coatings are connected with metallic rods, and the battery is charged by placing the internal coatings in connection with the prime conductor. The external coatings are connected with the ground by a chain from the metallic handles. In discharging the battery the outer coating should be touched first, and for large batteries great care is required.

Heat Developed by Electricity.—The passing of electricity from one body to another is generally attended with an evolution of heat sufficient to inflame gunpowder, melt, and even volatilize metals. The temperature of a good conductor of sufficient size is not, however, much affected by the transmission of a current of electricity; but if the size be disproportionate to the quantity passing through it, it will be heated to a greater or less degree. A number of interesting experiments may be performed to illustrate these facts. To convey strong charges of electricity,—

The Universal Discharger (*Fig.* 27) should be employed. It consists of two glass standards, C and D, through the top of which two brass wires, A and B, slide freely. These wires are pointed at the ends, but

e balls which either slide or screw on according to . The other ends are furnished with rings, and ove on hinge at *h h*. The balls rest on a table of oxwood, into which a slip of ivory is inlaid across he diameter, about one inch wide. To melt a thin ire we attach it to the two knobs of the discharger; nen connect B with the external surface of an electrical battery. By means of an insulating rod, R, we complete the circuit; and if the wire be fine enough

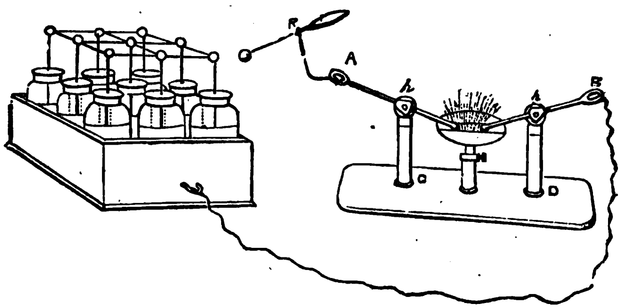


Fig. 27.

it will be instantly melted into globules, or volatilize. Gunpowder and other bodies may be inflamed in the same way, if some additional resistance be introduced into the path of the spark. If the path of the spark be entirely metallic, gunpowder will be merely scattered, but if a piece of wet string, six or eight inches in length, be introduced, either between A and R or *g* and the outer coating of the battery, the gunpowder may be readily fired. The increased resistance appears to cause an increased development of heat.

Disruptive Discharge.—The return of a charged Leyden jar to its normal state constitutes an electrical

discharge. This return to the normal condition may be effected in a variety of ways, and may therefore constitute different kinds of discharge. The most violent form, termed disruptive discharge, is when a communication is made, by means of a discharger, between the internal and external coatings of a Leyden jar. This discharge is attended with the sudden evolution of light and heat, and great expansive force. The distance through which the disruptive charge has been obtained, as between the metallic knob of the jar and the metallic knob of the discharger, is called the striking distance, or length of the spark (in a single jar it is about an inch); and this depends not only on the intensity of the charge, but also on the form of the conductor. The larger the conductor the greater the electrical charge required to pass through a given distance, because *the intensity is diminished in the inverse ratio of the square of the conducting surface.* Long sparks produced from the knob of a prime conductor, or an arrangement of jars, may be a foot or more in length. These discharges are attended with lateral divergence, the flashes are of a violet colour, and are very beautiful. The character of these flashes depends almost entirely on the form, area, and electrical intensity of the discharging surfaces, also on the kind of electricity on the conductor in which the spark or flash originates. If we diminish the surface of the knob on the prime conductor until we arrive at a metallic point projecting freely into the air, a very curious result follows. Instead of a brilliant explosion we have bushes or stars of light, attended by currents of air. If a short brass rod with a rounded end project from the prime conductor of a powerful machine it will send out a full brush of luminous rays, especially if a flat, imperfect conductor

be held in front of it. Faraday considers these phenomena as variations of the disruptive discharge. One is called BRUSH DISCHARGE, which is due to a number of small, distinct, and successive explosions, which terminate like a short conical brush.

The Glow Discharge is an almost continuous result, depending on the portions of air in contact with the surface of discharge becoming charged with electricity. It may be obtained by putting a pointed rod into the prime conductor. The glow will be observed passing from the point. Occasionally this glow will be seen around other parts of the conductor, and the presentation of large rounded surfaces will convert the glow discharge into a brush discharge. The influence of pointed conductors on electrically charged bodies attracted the attention of Franklin. He showed that, on presenting an uninsulated iron needle to the surface of an iron ball, its attractive force on a small thread immediately ceased. He also observed that this influence of a point in conducting off the electricity was attended with a current of air from the point sufficient to set in motion small models turning on a central axis, fitted up with cardboard vanes. Experiments may be used to illustrate these facts.

Accumulation of Electricity on the Surface.—When electricity is communicated to a conducting body, it resides merely upon the surface, and does not penetrate to any depth within. From a number of experiments intended to illustrate this fact we select the one first performed by Coulomb.

If a solid globe of metal, suspended by a thread of raw silk, or supported on an insulated glass pillar, be highly electrified, and two thin, hollow caps of tinfoil or gilt paper, with insulating handles, as represented in *Fig.* 28, be applied to it and then withdrawn, it will

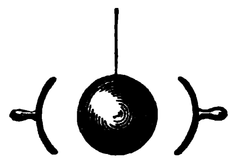


Fig. 28.

be found that the electricity has been completely taken off the sphere by means of the caps. An insulated hollow ball, no matter how thin its substance, will contain a charge of electricity equal to that of a solid ball of the same size, all the electricity, in both cases, being distributed on the surface. When the electric fluid is accumulated on the surface of a body, it tends to escape with a certain force which is called its TENSION, and the tension increases with the amount of electricity accumulated. In damp weather the tension is always feeble, because the electricity is slowly carried away by the moisture of the air. In a vacuum there is no resistance to the escape of the electricity, and the tension is nothing. The electricity in this case flows off as fast as generated. If we suppose electricity to be a force exerted by an elastic fluid capable of compression, like air, it would exhibit a certain amount of tension or reactive force, which would be as the density of the number of particles confined in a given space. The term tension may also be applied to the polarized particles between two conductors, and to a state of induction generally. When the particles of a body are forced from their neutral state into new electrical conditions, they are, as it were, in a constrained position, and this may be conceived to go on increasing up to its maximum limit. To this also the term tension is applied.

The accumulation of electricity on the surface of conductors is due to the attraction between the electricity on them, and the inductively decomposed electricity of surrounding bodies. Thus if we electrify

an insulated metallic cup (Fig. 28 *a*) we find the electricity wholly on the outside; but if we bring into the cup, so as nearly to touch it, an earth connected sphere, (Fig. 28*b*), we shall find that the + charge is on the inside of the cup, while the sphere becomes very active.

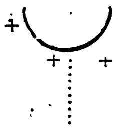


Fig. 28 *a*.

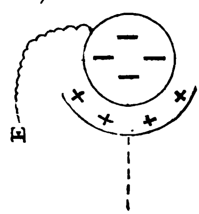


Fig. 28 *b*.

Electric Density.—The term density, or intensity, is more properly used in the following case:—Let a ball contain a quantity of electricity, which we will use as a unit, and call it one quantity; then if we load the same ball with twice as much, the density is two; thrice as much, the density is three; and so on. On a ball the density is the same throughout. On a plate it is greatest at the edges; and generally speaking, the nearer a conductor approaches to a point, the greater the density, and this naturally follows from the self-repellent character of the charge. The same electricity repels itself, and therefore the imaginary fluid will rush to the extreme parts of the body.

The discharge from points is always attended by an accompanying wind. Place a point on the prime conductor, and hold a candle to the point while the machine is in action. The candle will be blown out. The electric whirl may be used to illustrate this; it consists of a number of pointed wires, the points bent backwards, arranged in the form of a wheel; the centre is supported on a pivot. Connect the metal support with the prime conductor, and the whirl will turn round rapidly. The point enables the neighbouring air to assume almost instantly the same electricity as

the point itself has. There is, accordingly, repulsion between the two.

Intensity is somewhat different from tension, although there would be nothing incorrect in speaking of the intensity of tension, or the reactive force, as indicating its higher or lower degree, just as we speak of the intensity of light and heat; but in its application to electrical phenomena it expresses the activity of an electrified conductor, as shown by the electrometer. Thus the charge communicated to a battery may be taken by a quadrant electrometer, which expresses the intensity of the charge; and we speak of a jar being charged to a given intensity, and this is as the square of the accumulated quantity of electricity.

Mutual Relation between Tension, Intensity, Surface and Thermal Effects.—The same quantity of electricity as has been just described exhibits very different effects according as it is distributed on large or small surfaces; but in relation to thermal effects, surface appears to produce but very little influence, since a given charge, say 50 units, communicated to a Leyden jar containing 3 square feet of internal surface, or upon one containing 6 square feet, produces precisely the same effect upon the thermo-electrometer in either case.

Thermal effects are as the square of the accumulated quantity; that is to say, if 10 units develop 4 degrees of heat in being discharged through a wire of a given size, 20 units will produce 16 degrees, 30 units 36 degrees, and so on.

In verifying these experiments with the thermo-electrometer, especially where the interval passed over by the fluid on the scale is considerable, the effect apparently falls rather short of the law, but this is owing to the slight absorption of heat by the bulb of he thermometer during the small interval which

occurs between the passage of the discharge and the rise of the fluid to its maximum height. The distribution of an equal charge of electricity over two such Leyden jars as mentioned above will produce very different effects as regards tension and intensity. Tension being the measure of the striking distance, or the length of the discharge, it is only one-half with a double surface; whilst the attractive force, which is the measure of the intensity, will only be one-fourth with the double surface, the quantity of electricity in each case being the same. In all cases of the coated insulators or dielectrics, whether in the form of Leyden jars, coated glass or other plates, or coated telegraph wires, there are certain conditions which determine not only the amount of charge which can be taken up by a given coated surface, but the effect which the discharge of that quantity can produce.

A few well-determined axioms worked out, with the balance and thermo-electrometers before alluded to, will serve as a guide in these considerations.

1st. With any insulated charged conductor the statical intensity or power of attraction exhibited by it will be as the square of the quantity constituting the charge; and this holds good whether the conductor be simply insulated in the atmosphere, or form one of the coatings of a Leyden jar.

2nd. The thermometric effect of an electric charge, as ascertained by a wire passing through the bulb of the thermo-electrometer, is as the square of the quantity transmitted, other things being the same.

3rd. With any given area of coated or conducting surface, the tension or length of spark will be in the direct ratio of the charge. Thus, quantities of charge bearing the relations to each other of 1, 2, 3, 4, will give tensions or lengths of spark as 1, 2, 3, 4; but the statical intensities, as shown by attraction or inductive action,

will be respectively in the proportions of 1, 4, 9, 16, &c., corresponding precisely to the thermometric effect.

4th. The relation of the quantity to the intensity will depend upon the surface upon which the electricity is distributed; for instance, a double surface charged to the same degree of tension—that is to say, to give the same length of spark—will contain a double quantity; but the statical intensity and inductive or attractive action will remain the same, whilst the thermometric effect will be as the square of the surface or quantity, the thickness of glass being equal.

5th. If a given charge be distributed over conducting surfaces bearing the several relations of 1, 2, 3, 4, the thermometric effect will be unaltered; but the respective tensions or length of spark will be in the simple inverse ratio of the surfaces, viz., 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$; whilst the intensities or attractive power will be inversely as the squares of the surfaces, viz., 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$.

6th. The attractive or inductive influence acting between any two electrified surfaces is, with the same charge, inversely as the squares of the distances between which it operates. Thus, if the attracting discs of the balance electrometer be separated from each other by the several intervals, 1, 2, 3, 4, the force of attraction between them will be inversely as the squares of the distances, as will be shown by the quantity of weights in the scale-pan required to balance that force.

7th. The capacity of a conductor to receive electric charge will depend upon the amount of induction which can take place between it and a neighbouring conductor; and the nearer these can be brought together, the latter being uninsulated and the former insulated, the greater will be the amount of charge.

Now as there can be no doubt that it is the dielectric in contact with the conductors which receives the

charge, the conductors serving only to distribute or collect it, we may in the preceding law lose sight of the conductors beyond this function, and merely consider that the dielectric has its capacity for receiving charge increased by diminishing its thickness.

The capacity of a dielectric to become charged with electricity, or to take on a polarized condition, is termed its inductive capacity. Thus different dielectrics of the same thickness, all having equal coated surfaces, will take up very different degrees of electrical charge.

Influence of Form.—The shape of a body also exercises a great influence in the distribution of electricity over the surface. If a body is spherical, the electricity is distributed equally over the surface, as we have seen in the experiment with the two thin metallic hemispheres. To remove these hemispheres was to take away the surface of the sphere; and since by taking away the hemispheres all the electricity is taken away, we have proof that the electrical charge was entirely at the surface.

In an electrified sphere the same amount of attraction is shown for a pith ball, no matter where the contact is made on the surface; and this may be shown by an instrument called the PROOF PLANE, which consists of a small disc of gilt paper fixed at the extremity of an insulated thread of shellac or glass. The length of this stem, and of the support by which it is sustained, are so calculated that the small disc may supply the place of the fixed ball in the torsion balance apparatus, and act like it, when electrified, either upon the disc or the ball fixed at the extremity of the moveable needle. A point of the surface of a body is touched by the proof plane, and if this point be electrified it is immediately perceived, because the proof plane, when carried to the balance, immediately

acts on the moveable needle. By this mode we can prove that a hollow metal sphere does not present the slightest trace of electricity on its inner surface, even when its outer surface is strongly electrified. When a body is elongated or pointed, like a cone supported in a horizontal position, different results are obtained with the proof plane, which show that the pointed end is more highly charged than the other extremity of its surface. This shows that electricity tends to accumulate or flow towards the pointed portions of bodies. This accumulation at points gives rise to a high tension; the electricity overcomes the resistance of the air, and escapes. All pointed metallic bodies soon lose the electricity imparted to them, and often the escape, with its accompanying current of air, can be felt by placing the hand in front of the point. If a lighted taper be substituted for the hand, it will be blown out by the current proceeding from a point fixed in the conductor of an electrical machine.

A strong smell of ozone, an allotropic form of oxygen, is also perceived by bringing the nose near to this current. If the flow takes place in a darkened room, a feathery jet of faint light is observable. This power of points was early noticed by Franklin, and used in constructing lightning conductors.

Atmospheric Electricity.—The complete identity between lightning and the electric spark was first shown by Franklin. The existence of electricity in the atmosphere is not confined to clouds, for it often exists when no trace of clouds is visible. In this case the electricity is positive. It is most abundant in open spaces, and at considerable elevations. Mr. Crosse gives the following results of his observations:—

1. The electricity of the air is almost always positive; increases after sunrise, diminishes towards noon;

increases again towards sunset, and then decreases again towards night, after which it again increases.

2. The electrical state is disturbed by fogs, rain, hail, sleet, and snow. It is negative when these first approach, and then changes frequently to positive, with subsequent continued changes every few minutes.

3. Clouds also, as they approach, produce similar disturbance; sparks from the insulated conductor follow each other in rapid succession, so that an explosive stream of electricity rushes on the receiving ball, which it is wise to let pass off into the earth. Similar effects frequently attend a driving fog and a smart heavy rain.

The principal causes which are supposed to produce electricity in the atmosphere are evaporation from the earth's surface, chemical changes which take place on the earth's surface, and the moisture, condensation, expansion, and variation of temperature in the air.

The electrical conditions of a thunderstorm may be studied in the electrical conditions of a Leyden jar. The atmosphere becomes a great coated plane, or fulminating square, of which the charged cloud is the insulated and the earth's surface the uninsulated terminating conducting planes. The phenomena of thunder and lightning are due to the disruptive discharges through the intervening stratum of air. The grandeur and magnitude of the effect depend on the tension. The same phenomena attending many electrical experiments may also be observed. Thus lightning is often of a wavy, crooked, or zigzag appearance; at other times it is straight and brilliant, or spreading out in sheets; and sometimes it is globular, having the appearance of a ball of fire.

The Return Stroke is a violent and often fatal

stroke felt by men and animals at a considerable distance from the place where the lightning strikes. This phenomenon is due to the inductive influence exerted by an electrified cloud upon bodies beneath it, which are all in an opposite electrical condition to that of the cloud. Now if a discharge takes place at any point, the cloud returns to its neutral state, induction ceases instantly, and all the bodies electrified by induction instantly return to a neutral condition. The suddenness of this return is what constitutes the return stroke. We may illustrate the return stroke by placing a living frog near an electrical machine in operation. Every time the machine is discharged, by placing the finger on the prime conductor, the frog experiences a shock, which is nothing else but the return stroke.

Effect of Pressure.—The pressure of the atmosphere influences greatly the effects of tension. If discharges be made in an air-pump receiver, the length of spark will increase as the air is exhausted, and in a vacuum a Leyden jar may be made to discharge with a spark three feet or more in length, whilst the same discharge in the air would not be an inch long. It is for this reason that zigzag sparks of lightning may often be seen of an enormous length in the higher regions of the atmosphere.

The aurora borealis affords a striking example of the mode in which highly charged portions of air discharge electricity into other portions oppositely charged, without the assistance of conducting clouds to concentrate and help the discharge along.

The aurora borealis may be beautifully imitated by causing a current of sparks from a good electrical machine to fall upon the cap of an exhausted receiver of 3 to 10 feet in length and 4 inches diameter. The electricity streams down in the interior, resem-

bling thousands of illuminated threads twisted in all directions.

The absence of moisture in the atmosphere in the polar regions, especially in the winter season, renders it an excellent non-conductor; the loss of its moisture and condensation by cold gives rise to electrical changes. In the upper regions there is an atmospheric current constantly proceeding to the poles from the tropics, and in the lower stratum a current passing from the poles to the equator. These currents are necessarily in different electrical states, and the attenuated condition of the higher portions of the atmosphere affords facility for the restoration of equilibrium between these differently electrified strata of the air.

A Lightning Conductor is a rod of metal placed upon the top of a building or mast of a ship, and extending to the ground or sea, with a view of conducting away at once any discharge of lightning which may fall upon it. This metallic line of communication may be in the form of a rod or flat strip, or it may be a wire rope. Sir W. S. Harris employed flat stout strips of copper for the protection of shipping. These strips are let into grooves ploughed out in the back of each mast, the connections between the upper and lower masts being maintained by a strong metal drop in the form of a hinge fixed on the top of each mast, which hangs forward and touches the conductor in all positions. The conductors on the lower masts either pass down through the hold and are connected with metal bolts which pass through the keelson and keel, and touch the copper sheathing, or they are continued from the mast under the deck and out through the side of the ship, and thus down to the sheathing.

Metallic rods or wire ropes are best suited for buildings, but they are very objectionable to ships.

The top of the conductor should be pointed, and extend two or three feet above the object on which it is fixed, and the lower part of the conductor should branch in two or three directions away from the building, and be carried if possible to a well or moist stratum of the ground. If the building be extensive, it will require several conductors.

Lightning conductors should never be insulated; but all extensive metallic arrangements about a building, such as lead gutters, &c., should be connected with it. It is no uncommon thing to see a single lightning conductor fixed against one of the four turrets of a church, under the impression that a conductor is capable of protecting a given area around it. All the turrets should be brought into metallic communication with it.

If a conductor be jointed, its joints should be secured by screwing or riveting. Copper is the best conductor; a half-inch copper rod has never been melted by a discharge of lightning, hence we consider that size ample. If the conductor be of iron, three-fourths of an inch to an inch in thickness will suffice. If a conductor be not connected with a good conducting stratum in the earth, the lightning may leave the conductor, and fly to any neighbouring conductors, such as gas fittings, that are always in connection with a good conducting train; the effective disposal of the lightning after it reaches the ground is therefore a matter of the most vital importance.

If we bear in mind the fact that the damage by lightning occurs not where metals are, but where they are not, and that metals annihilate distance as regards the track of the lightning discharge, we can by exami-

nation of the fortuitous arrangement of conducting substances throughout a building indicate with certainty not only the course the lightning will take, but the places where damage will occur.

It often happens that a few strips of copper will, in the hands of the electrician, suffice to join up detached portions of metal, so as to form a continuous conducting line to the ground, and thus protect a building as effectually as if it were provided with a lightning conductor fitted on the most orthodox principles.

Lightning chooses the path of least resistance, and is mathematically correct in its selection of it. When the lightning has a choice of circuits, all of them more or less resisting, though still possessed of a certain amount of conducting power, it will frequently distribute itself amongst them in its passage to the ground according to their conducting capacities. This may be illustrated by laying a strip of gold-leaf about one-eighth of an inch wide in the form of a parallelogram, say about two inches square, on a sheet of paper. If now the charge of an electrical battery be made to pass through one of the sides of the square, the shock will be seen to divide, the main portion passing with a bright flash and loud report in the short line, and the remainder through the other three sides of the square, the relative quantities passing in each circuit being marked by the degree of deflagration of the gold, and colour of the stain upon the paper.

It is advisable to terminate the upper end of a conductor by a sharp point, upon the principle that points prevent the accumulation or reduce the intensity of the electrical charge in any conductor to which they are approximated. This they do by affording, as it were a rapid supply of the opposite electricity, or by

neutralizing the polar condition of the stratum of air between the oppositely electrified surfaces of the clouds and earth. The atmosphere always contains free electricity, sometimes positive, sometimes negative. The electricity of the ground, according to Peltier, is almost always negative. In general the clouds are always electrified, either positively or negatively. The lightning discharge is an electric discharge which strikes between a thunder-cloud and the earth. The latter, by the induction from the electricity of the cloud, becomes charged with an opposite electricity; and when the tendency of the two electricities to combine exceeds the resistance of the air, the flash passes. Lightning generally strikes from above, but ascending lightning is sometimes seen. This is the case when the clouds are negatively and the earth positively electrified.

Action of the Lightning Conductor.—Franklin supposed that the conductor preserved buildings by drawing off the electricity of the clouds. This, however, is not the case. When a positively electrified cloud arises over the earth, negative electricity collects in the earth under it, and the conductor forms a convenient path for this negative to ascend and neutralize the positive cloud. Occasionally the accumulation of electricity is so great that this action does not prevent a discharge, which will be along the conductor, for that presents the line of least resistance.

Primary, Secondary, &c., Currents of Frictional Electricity.—These may be obtained in a series of spiral wires, or helices, by discharging a Leyden jar battery through the first spiral; a second spiral has inductively produced in it a secondary current of considerable power, and if the second spiral is connected with a third spiral, so that the

secondary current passes along it, then this secondary current will act as the primary current of the first wire towards a fourth spiral, producing in it a tertiary current, or current of the third order; and this may be continued to currents of a higher order, each of which will give electrical effects.

Effects of the Electric Discharge.—The recombination of the two electricities may be sudden, as in the discharge of a Leyden jar, or it may be continuous, and so of the nature of a current, as in the glow or brush discharge, according to the nature of the conductors.

Physiological Effects.—Animals recently killed are subject to violent muscular contractions, as if they were returning to life; while living animals feel what is known as a shock, or series of shocks, consisting of violent contractions of the muscles. The shock wil be felt in the wrist, shoulder, or stomach, according to the strength of the charge. One discharge may be passed through a number of persons, if they make a conducting chain by joining hands. The shock from a large Leyden jar battery is dangerous.

Chemical Effects.—The decompositions of compounds and the recombinations of elements.

Examples :—

$$H + Cl = HCl$$
$$N + H_3 = NH_3$$
$$C_2H_4 = C_2 + H_4$$
$$H_2S = H_2 + S$$
$$NH_3 = N + H_3, \text{ \&c.}$$

There is a marked difference, however, between the effects produced by frictional or statical electricity, and those produced by voltaic or dynamical electricity. They are certainly the same in kind, but the statical

effects are neither so well developed nor so varied as in the case of voltaic electricity. EXPERIMENT 1.—In a suitable glass tube, called a eudiometer, put two volumes of hydrogen gas and one of oxygen gas, pass the electric spark through them by means of two platinum wires fused into the glass. Not more than one cubic inch of hydrogen, and half a cubic inch of oxygen should be used in such an experiment. The two gases will combine with explosion, and the result will be H_2O, or water, on the surface of the glass.

EXPERIMENT 2.—The electric pistol or cannon is exploded in a similar manner. The resulting steam or vapour of water drives out the cork with immense force.

EXPERIMENT 3.—Take an elliptical piece of filtering paper saturated with iodide of potassium, place it on glass, connecting one end of the paper with the ground. Pass sparks to the other end; brown spots will show the separation of the iodine.

Magnetic Effects.

EXPERIMENT 4.—Discharge a battery through a copper wire, place a piece of steel wire at right angles, either near to it or across it. The steel will be magnetized. If the discharge passes above the steel, that end of the steel will point to the N., which would be on your left hand if you were walking along the copper wire in the direction in which the discharge takes place.

EXPERIMENT 5.—Or place the steel within a glass tube, around which is a copper spiral. Discharge the battery through the spiral, and the steel needle will be magnetized. If the spiral be a right-handed spiral, like a corkscrew, the end of the steel which points to the N. is the end about which the spiral is wound as the discharge *leaves* the spiral.

Heating Effects.

EXPERIMENT 6.—In a metal spoon place some ether, take the electric spark through the liquid, and it will burst into flame.

EXPERIMENT 7.—A person standing on an insaluting stool, with one hand on the prime conductor, may light coal gas with a finger of the other hand, from which a spark will pass to the metal burner.

EXPERIMENT 8.—Pass the discharge from a powerful battery through a fine metallic wire; it will not only become red-hot, but will actually volatilize.

Illuminating Effects.—These may be varied at the will of the experimenter. The better the conductors the more brilliant the spark. Between the charcoal points the spark is yellow, between two balls of silvered copper it is green, between two balls of wood or ivory, crimson. In oxygen gas it is white; in hydrogen, reddish; in mercury vaporized, green; in carbonic acid, green; and in nitrogen, blue or purple. By arrangement of lozenge-shaped pieces of tinfoil on tubes, squares, and bottles, every conceivable design may be imitated, and beautiful illuminated pictures obtained, which of course look much more brillant when shown in a dark room.

It will, no doubt, be noticed that statical electricity has paid but slight contribution to the useful arts. Its transitory nature will account for this to a great extent It is used in war for firing mines, and also for exploding gunpowder, &c., in coal and other mines. In Experiment 8 we saw how readily a metallic wire may be made red-hot: of course if this were surrounded by a suitable substance, a violent explosion would ensue. The operators may be at any safe distance away while this takes place, for wires may be continued to any desired place.

VOLTAIC ELECTRICITY.

In a previous article it has been stated that when electricity passes through a conductor in a determinate direction it is termed a current. This term, however, is seldom applied to statical electricity; for although, both in the case of the spark from the electrical machine and the shock of the Leyden jar, the electricity may be made to pass through a conductor, yet this would be merely termed a discharge, the action being sudden and the quantity definite. The term "current" implies a certain continuity of action, however short its duration. The phenomena yet described and included in the term statical have been accompanied by certain mechanical effects, such as attraction and consequent motion in the attracting bodies, mechanical disruption of the particles of air, fracture of solid substances, production of sound, and all these at sensible distances. These effects depend upon the distinguishing characteristics of intensity and tension, the absolute quantity of electricity producing them being extremely small.

The conditions under which the phenomena are developed, viz., either on the surfaces of insulating substances or on insulating conductors, are such as to favour the full and uncontrolled action of this intensity.

The class of phenomena now about to be considered under the head of dynamic or voltaic electricity will be found to present very different characteristics.

Being developed in the midst of good conductors there is no possibility of perfect insulation, and consequently, as there can be none of the accumulations which give rise to the mechanical phenomena peculiar to statical electricity, they entirely disappear, and in

their place new phenomena present themselves, which if we except the correlative effects of magnetism, take place at insensible distances, and amongst the molecules of the substances concerned in the development of the electrical actions.

Chemical action appears so intimately connected with the development of the phenomena of dynamic electricity as to have been considered the chief source of it; but whether chemical action evolves electricity or whether the mutual influence of bodies upon each other whose electrical relations differ, originates chemical actions, it is difficult to determine. Sir Humphry Davy has assumed that all chemical combinations are the result of the union of bodies in opposite electrical conditions, and by suitable arrangements it may be shown that the greater the difference between the electrical states of the combining bodies, the more intimate is the union between them.

Although static effects from chemical action are not discovered unless in multiplied voltaic arrangements, yet by means of the ordinary gold-leaf electroscope electrical attractions and repulsions are easily exhibited.

It was not, however, by the observation of phenomena of this kind that galvanic or voltaic electricity was discovered. Galvani, or rather Galvani's wife, was the first who noticed the electrical effects which gave rise to this new branch of scientific research. She was skinning some frogs for the purpose of making soup, and as the hind legs were the only portions required, several of these prepared limbs were lying upon the table in the professor's laboratory. Some of her husband's students were experimenting with an electrical machine on the same table, and she observed that whenever a spark was drawn from the machine,

the prepared limbs were violently convulsed if they happened to be touched at the same moment. On Galvani's return the experiments were detailed to him, and he lost no time in repeating them under a variety of conditions. These convulsions were caused by what is termed the return stroke, or the inductive discharge arising from the sudden return of the surface of the table to its neutral condition when the action of the electrified conductor which had been inducing an opposite electrical state in it was withdrawn by the discharge of a spark. The nerves of the frog served as an electroscope, delicate enough to be acted upon by the minute spark thus occurring between them, as part of the conducting surface of the table, and the instrument with which they were touched.

Galvani, however, found that by touching the exposed nerves with two dissimilar metals at the same time, whilst the metals were also in contact with each other, similar convulsions could be produced without the aid of an electrical machine; and to these effects he gave the name of Animal Electricity, ignorant of the fact that the contact of the two metals excited electricity enough to affect the nerves of the frog.

Volta, who repeated these experiments, thought he discovered in the use of the two dissimilar metals evidences of chemical action, and this gave a different direction to his researches, which resulted in the verification of his conjecture.

He found that by certain contrivances by which he could multiply the effects due to a single pair of metals by increasing the number of pairs, he could proportionally augment the electrical effects, and he then obtained unmistakable evidences of chemical action, also proportionate to the number of the elements which he employed.

Sultz found that if a piece of zinc and a piece of silver or copper were placed one above and the other below the tongue, a peculiar sensation was felt in the tongue whenever the outer edges of the metals were brought into contact with each other, which he attributed to electrical action.

He also found that when two plates of copper and zinc were separated from each other by a piece of moistened cloth, especially if moistened with acidulated water, much more powerful muscular contractions were produced in the limbs of a dead frog when a wire from each metal was brought in contact with them.

Volta increased his combinations, and further improvements have been since made. What is known as a Voltaic pile is arranged as follows:—Upon the table is placed a plate of zinc, upon this a piece of cloth, moistened with salt and water, and upon this again a piece of copper, of a size corresponding to the other plates. Zinc, cloth, and copper following in regular series, to the number of fifty or a hundred, finishing with a copper plate on the top. To prevent the series from falling they were supported between rods of baked wood or glass, or occasionally, to prevent the water from being squeezed out by the weight of the plates, the whole series was turned down on its side. Wires attached to the ends of this arrangement show that these are in opposite electrical states, the one connected with the lower or zinc end giving negative electricity, and that from the upper or copper end showing positive electricity. The electrical actions are not between the metals which are in contact with each other, but between those which are separated by the cloth. Volta placed a zinc plate above the copper, and a copper plate below the zinc; but

these metallic plates merely acted as conductors to exhibit the electrical state of the others to which they were applied, and which alone were concerned in the generation of electricity through the agency of the moistened cloth. This upper zinc

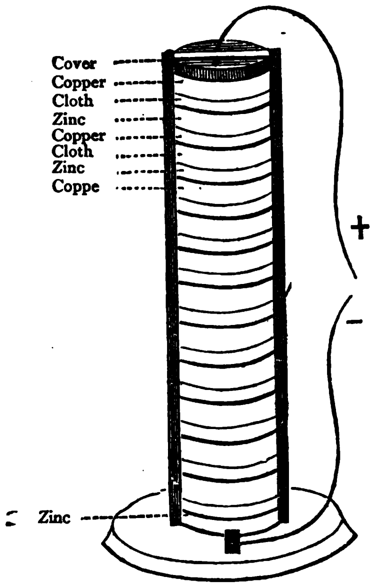


Fig. 29.

plate can therefore be dispensed with, as contributing nothing to the general electrical excitation, and the upper end will then be copper, forming one of a pair of excited electrical elements. In like manner the lower plate at the base can be dispensed with, as it

serves only as a conductor to the zinc plate on which it rests, and which really is the terminal element of the series. The exciting triads will then stand—copper, cloth, zinc; copper, cloth, zinc, &c., when it will be seen that the true copper end gives positive electricity; and this holds good in all galvanic arrangements, whether voltaic piles or in arrangements of couples in cells to be hereafter described.

In a pile which is insulated, one half is found to be electrified positively, and the other half negatively, the middle being neutral. The tension of the electricity at either end increases with the number of pairs of plates, independently of their size. The tension is greatest at the extremities, and these extremities are called poles, and the wires which are attached at the two poles for completing the circuit are called electrodes. So long as these electrodes are separated the pile shows no action, but on being brought together a spark is seen to pass, which arises from the recombination of the two electricities. This spark does not discharge the pile, as in the case of a Leyden jar, but a continual succession of sparks may be observed, showing that decomposition is kept up in the pile. If the two wires are actually connected the sparks cease, but the action is still going on, and this continual flow of electricity is called an electric current. According to the two-fluid theory, there are, in fact, two currents flowing in opposite directions; but it is found convenient to consider only one, namely, that which flows from the positive to the negative pole.

A voltaic pile was rather an awkward arrangement. A number of metallic plates placed horizontally on each other would press out all the acidulated water, or other fluid, from the cloth by which these plates were

separated, and so interfere with the action of the pile. To avoid this, Volta introduced—

The Couronne des Tasses, or crown of cups, where glass vessels contained water acidulated with sulphuric acid, and the plates of copper and zinc were soldered to the ends of a bent wire or strip of copper, as shown in *Fig*. 30. When the circuit is closed by joining the ends of the wires, gas is actively evolved; but when the current is broken, the evolution of gas ceases.

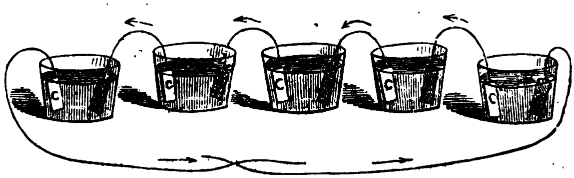


Fig. 30.

Simple Voltaic Circles or Pairs.—The clear conception of the various phenomena which take place in a single cell is necessary for the comprehension of the *rationale* of the different processes employed for developing electricity under the most advantageous circumstances.

If a plate of zinc * and a plate of copper, each furnished with a piece of conducting wire, be immersed in a cell of dilute acid, the only actions to which they will be subject will be those due to the simple chemical relations of the metals to the acid

* Pure zinc must be used. Ordinary commercial zinc will give violent action in the acidulated water with slight electrical results; it may, however, be rendered equal to the pure zinc in this respect by amalgamating it with mercury. Dip the zinc into acid to clean it, then rub mercury over the zinc, and it will adhere.

itself, and if this be capable of oxidizing both metals, both will be attacked and oxidized by it. But if the metals be now joined by their conducting wires, they are immediately brought to act upon each other in their electrical capacities, and an inductive or polarizing action is set up between each, and the acid menstruum included between them.

This polarizing action will be considered more in detail in its proper place; it is sufficient here merely to indicate the effects which are produced, suspending the consideration of the causes for a time.

The two plates, then, of zinc and copper immersed in the acid, and connected externally by a wire reaching from one to the other, form what is termed a closed circuit; and if the wire be cut in two the circuit is said to be open.

The circuit, then, essentially consists of two parts,— one the generating, or, as it is sometimes called, the electrolytic or battery circuit, and the other the conducting or external circuit; and these two circuits exhibit different characteristics.

In the battery circuit electrical polarization and chemical decomposition take place, whilst in the external or conducting circuit the phenomena of heat, light, and magnetism are produced under suitable circumstances.

Taking a zinc and copper plate immersed in dilute acid and connected by an external wire, the zinc and copper assume opposite electrical conditions in respect of their opposed surfaces, the zinc surface being positive and that of the copper negative. Since all chemical compounds result from the union of two oppositely electrified bodies, the water contained in the cell constitutes an element of this kind, the oxygen and hydrogen of which it is composed being electro-

positive and electro-negative with regard to each other.

Under the electrical influence of the two plates these affinities are loosened, as it were, the opposite electricities of the copper and zinc being stronger, and sufficient to attract the oppositely electrified elements of the water in different directions; oxygen, being electro-negative, is attracted to the zinc, and combining with it forms oxide of zinc, ZnO, and this ZnO becomes a base which can again be acted upon by the SO_3 of the dilute acid H_2SO_4, producing $ZnSO_4$ or sulphate of zinc, the crystals of which may be constantly noticed on the porous cells or at the bottom of batteries, where H_2SO_4 and Zn are used. The hydrogen, being positive, is attracted by the negative copper, and being incapable of combining with it, escapes in the form of gas, chemically represented as H_2 free.

Sometimes this hydrogen adheres to the surface of the copper in the nascent condition, and refuses to be completely converted into gas. When this is the case the negative condition of the copper surface not only becomes neutralized by the positive film of hydrogen upon it, but also the H sets up opposing currents which gradually lower the intensity, and the electrical action ceases, because the opposite surface of the zinc and copper no longer differ in electrical condition: the negative metal is then said to be polarized. Supposing this disturbing influence not to arise, the water in the cell is slowly decomposed, the oxygen being drawn to the zinc and combining with it, and the hydrogen being attracted to the copper surface and liberated in the form of gas. The addition of a little acid, by increasing the conducting character of the water, and by dissolving the oxide of zinc, thereby keeping the

surface of the zinc plate in a good electrical condition, greatly facilitates the development of electricity.

The result of these actions is the origination of a current of electricity, taking its direction from the zinc plate through the acid to the copper plate, and from the copper plate through the wire back again to the zinc, thus keeping up a constant circulation in one determinate direction. The supporters of the two-fluid theory maintain that whilst positive electricity is flowing in one direction through the different parts of the circuit, an equal current of negative electricity is flowing in the opposite direction; but for all practical purposes the negative current is lost sight of, and the positive current alone is recognized. Hence, when in electrical language the direction of a current is spoken of, the passage of a single current from positive to the negative is always meant. With this view of the question let us examine the electrical states of the various parts of a voltaic pair with a closed circuit. It would be quite evident, from a moment's consideration, that the terms positive and negative are simply terms which indicate more the dynamic than the electrical character of any parts of the circuit, although when the circuit is divided in any part the separate electrical conditions are easily detected. Let the wire circuit be divided, say in the centre; the dissevered ends will exhibit opposite electricities, the one on the copper side being positive while that on the zinc side is negative. One half of the wire, therefore, appears positive and the other negative from position.

But every part of the wire is at the same time both positive and negative; for imagine the wire to be composed of an infinite number of minute discs with their faces in contact, and represented by the transverse section of the wire: every face looking towards

the copper will be negative, because it is receiving the current flowing into it; whilst all the faces looking towards the zinc will be positive, because they are sending on electricity through their neighbours towards the zinc; and in whatever part the circuit is cut, two discs are formed looking in opposite directions and exhibiting opposite electrical conditions. It is for this reason that the zinc and copper plates are each at the same time both positive and negative in relation to the circuit. The zinc plate is positive when we contemplate it as sending forward electricity through the fluid of the copper, but it is negative when we look at it as receiving back electricity through the wire.

For the same reason the copper is positive when viewed in the light of sending on a current through the wire to the zinc, but negative in the light of a recipient of the electricity which has been sent to it through the acid from the zinc. Lastly, suppose the wire circuit to be cut in twenty places, and suppose the current, through the intervention of imperfect conductors, still to be flowing, all the ends of the wires into which the current enters will be negative ends, whilst all the other ends which the current leaves, or out of which it is passing, will of necessity be positive; and under suitable conditions these disjoined wires will exhibit at their respective ends the same chemical phenomena as the opposite ends of a voltaic battery. In speaking of the electrical conditions of a pair of plates it is necessary to distinguish whether they are considered in relation to each other through the acid or through the metallic circuit. The copper is the negative metal and the zinc the positive in relation to each other in the acid; but the copper is the positive metal and the zinc the negative when considered in

relation to the circuit, for the current flows from the copper through the circuit to the zinc.

Causes which facilitate or control Electrical Development.—The current of the voltaic series varies much in its strength and quantity according to circumstances, and this affords an interesting field of inquiry. The decomposition of water is generally looked upon as the great source of electrical action, and the faster this can be effected the greater the quantity of electricity produced in a given time. The elements of water, however, cannot be made to separate from each other unless at the same moment that one is taken up the other shall be equally well provided for.

In the simple pair of zinc and copper, the rate of combination of the zinc with the oxygen resulting from their mutual attraction is governed by the facility with which the copper can get rid of the hydrogen in the form of gas, and it will be found that this disposing of the hydrogen is the great secret of success in all galvanic arrangements.

It has been already remarked that the hydrogen sometimes adheres to the copper, thus polarizing it and stopping the action of the battery. Roughening the surface of the copper, by scratching it with emery, by piercing it with an immense number of fine holes, so as to throw up sharp burs like a grater, or by etching its surface with acid, &c., materially increases the power of the battery, since fine points facilitate the escape of hydrogen.

Smee's Battery.—*Fig.* 31. It was upon the foregoing principle that Mr. Smee constructed his admirable and simple battery. He substituted silver for copper, and roughened the surface of the silver by depositing upon it, through the agency of electricity, platinum in a very finely divided state. It is there-

fore called platinized silver. From the innumerable points thus presented the hydrogen escapes with a rapid and powerful effervescence, thereby setting the oxygen more at liberty to combine with the zinc. It

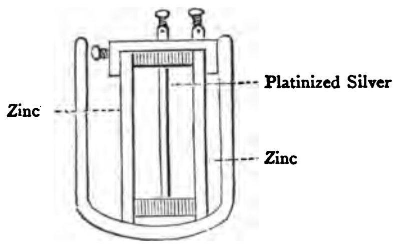


Fig. 31.

is usual with the Smee's battery to place a zinc plate on each side of the silver one, for since electricity is developed on the opposite surfaces, there is no reason why both surfaces of a plate, especially if it be an expensive one, should not be put in requisition.

Instead of silver the coke scales found in gas retorts may be used with advantage. They are rubbed down into plates and platinized.

It has been found that coating the surface of the zinc with quicksilver prevents the acid from attacking and dissolving it when the circuit is not completed, an action formerly very detrimental to the production of electricity. The Smee's battery, therefore, is the most perfect and powerful arrangement, based on the principle of liberating gaseous hydrogen.

Chemical reactions in Smee's battery :—

$$(1)\ H_2O + Zn = ZnO + H_2 \text{ free.}$$
$$(2)\ SO_3 + ZnO = ZnSO_4.$$

The first result is the decomposition of the water,

giving free hydrogen gas and zincic oxide. The second is the zincic sulphate, which will crystallize out in a short time.

Hare's Calorimeter.—Dr. Hare, of Philadelphia, discovered that the most intense effect was produced at the moment when a pair of zinc and copper plates were immersed in the acid, and he therefore contrived his battery so as to keep his plates suspended in the air when not in use, and to lower them into the acid when the current was wanted. It does not appear that Dr. Hare was acquainted with the cause of this increase of power, which arose from the following circumstances:—

Dr. Hare's exciting fluid consisted of dilute sulphuric, nitric, and muriatic acids mixed; the nitric acid in particular has the power of oxidizing copper, and during the time that the plates were lifted out of the acid and exposed to the air, the copper plates became oxidated by the small quantity of acid adhering to them. This oxide was the great secret of the power, as will be presently seen.

When these oxidated copper plates were re-immersed in the acid, the hydrogen which would have been liberated in gas from a clean copper surface was instantly absorbed by the oxide of copper, and disposed of more readily in combining with its oxygen and reducing it to the metallic state, than in assuming the form of gas. Dr. Hare always observed that the longer the plates had been exposed to the air, the more powerful was the effect at the moment of immersion. The effects were, however, transient, as can be easily understood, for they must of necessity diminish when all the oxide has been reduced to the state of metal.

If, then, it were possible to keep the copper plate

constantly supplied with an oxide of copper, this intensity of action would be maintained so long as this reduction of the copper could go on.

Dr. Daniell's Battery is founded on this very principle (*Fig.* 32). It consists of an outer glass vessel, A, into which is placed an open cylinder of copper with perforations in the side, and a perforated rim, or gallery, at

Fig. 32.

E. A binding screw is attached to the copper cylinder, C. Into this copper cylinder a porous cylinder, D, of earthenware is introduced, closed at the bottom. Into this porous cylinder a rod of amalgamated zinc, Z, is introduced, with a binding screw at the top. Instead of porous earthenware cells, an animal membrane may be employed, such as an ox gullet. A dilute solution of sulphuric acid is introduced into the porous tube, and the outer copper cylinder and glass are nearly filled with a saturated solution of the sulphate of copper. Solid crystals of this salt rest on the rim, E, which dip into the solution, and gradually dissolve as the battery comes into action. When a connection is made between the rod of zinc and the

copper cylinder, electrical action commences. The oxygen of the acid solution combines with the zinc, and the liberated hydrogen passes through the porous cell to the copper. It does not escape in the form of gas, but enters into combination with the oxygen of the sulphate of copper; and the metal being thus deprived of its acid is reduced to its metallic state, and deposited on the interior of the copper cylinder. By the continual absorption of hydrogen and the deposition of metallic copper a bright conducting surface is maintained, which not only increases the intensity, but secures greater steadiness of action. In ordinary batteries the escape of hydrogen is not only very disagreeable, but it prevents contact between the fluid and the metal, and causes the zinc to be deposited on the copper. When this occurs, not only is a portion of the surface rendered useless, but counter-currents are set up from a number of small batteries formed on the surface, which more or less neutralize and diminish the effect of the battery. The constancy of action peculiar to the battery just described has obtained for it the name of the constant battery. When the battery is not in use the zinc rod is taken out and wiped: the membranous bags or porous cells are emptied of their solution, filled with water, and suspended from a wooden frame. A battery formed of ten copper cells, 20 inches high and $3\frac{1}{2}$ in diameter, and zinc rods $\frac{5}{8}$ in diameter, will maintain a piece of platinum wire, $\frac{1}{30}$ in diameter, 6 inches long, at a red heat, and liberate 12 cubic inches of the mixed gases per minute.

Since the copper cylinder is not injured by the action of the sulphate of copper, but really has its mass increased, the glass vessel containing the arrangement may be dispensed with, and the copper cylinder, by

having a bottom soldered to it, may be made to contain the sulphate of copper with the diaphragm and zinc. In this case the copper cylinders are better for standing upon a disc of gutta-percha or india-rubber, for the purpose of insulation. Although the disposal of the hydrogen by appropriating it to the reduction of the copper produced a great increase of effect, yet part of the energy was lost in the neutralization of the affinity already existing between the copper and the oxygen.

Chemical reactions in Daniell's battery:—

(1) $H_2O + Zn = ZnO + H_2$ free.

(2) $H_2 + CuSO_4 = H_2SO_4 + Cu$.

The first result is the production of zincic oxide and free hydrogen. The second result is sulphuric acid and metallic copper. The hydrogen passes through the porous cell to the sulphate of copper, causing the metallic copper to be deposited on the copper cell, and of course producing sulphuric acid by combining with the remainder. This passes through the porous cell to the zinc, strengthening the action of the acidulated water in the porous cell.

Grove's Battery.—From the preceding considerations it might reasonably be inferred that if the negative metal could be supplied with a fluid containing oxygen in a looser state of combination, and requiring less expenditure of force on the part of the hydrogen to effect a combination with it, effects would be produced proportionally great. Such an arrangement is Grove's nitric acid battery.

The principle is the same as that of the Daniell's battery; nitric acid being substituted for the sulphate of copper, and a sheet of platinum for the copper cylinder, it being necessary to have a metal in contact with the nitric acid which would not be dissolved by

it. Here, then, we have the most favourable conditions for the development of electrical power; the zinc is able to seize the oxygen of the water more rapidly because the hydrogen is so much more readily got rid of by absorption into the nitric acid, the easy decomposition of which offers very little impediment to the combination of the hydrogen with its oxygen.

The platinum plate in contact with the nitric acid is virtually a plate of oxygen rendered metallic. *Fig.* 33 represents a section. A B C D is a trough of

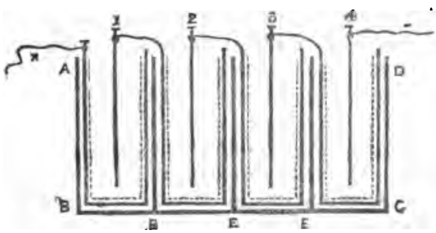


Fig. 33.

stoneware or glass, divided into compartments by the partitions E E E, which make four acid-proof cells. The dotted line represents porous cells of unglazed porcelain of pipeclay, and so much smaller than the cells as to allow about double the quantity of liquid that is contained between the outer surfaces of the porous cells and the earthenware cells. The four central lines, 1, 2, 3, and 4, are plates of amalgamated zinc, and the lines which bend under the porous vessels are sheets of platinum, which are fixed to the zinc plates by small clamp screws. Dilute

sulphuric acid is poured into the porous cells, into which the zinc is placed; and outside the porous cells, in contact with the platinum plates, is concentrated nitrosulphuric acid, formed by equal mixtures of the two acids some time before being used. During the action of this battery there is an abundant evolution of nitrous acid gas, and this is absorbed by covering the battery with an apparatus containing quicklime.

With a battery of this kind, consisting of four pairs of plates, and each zinc and platinum plate having a surface of 14 square inches, and the whole occupying a space of not more than a cube of 4 inches, Mr. Grove liberated 6 cubic inches of mixed gas per minute, and raised a platinum wire of $\frac{1}{40}$ in. diameter, and 7 inches long, to a red heat; and ordinary metal wires are melted into globules.

When the battery is first put into action, by uniting its poles, the nitric acid becomes first yellow, then green, then blue, and ultimately hydrogen is evolved from the surface of the platinum plates. The oxide of zinc does not pass through the porous cells, but remains on its own side, which keeps a clean surface, and maintains the energetic and constant action of the battery.

Chemical reactions in Grove's battery:—

$$(1)\ H_2O + Zn = ZnO + H_2 \text{ free.}$$
$$(2)\ H_2 + 2HNO_3 = 2NO_2 + 2H_2O.$$

The first result, as before, is the liberation of hydrogen, which passes through the porous cell, combining with the nitric acid, and producing water, and the peculiar heavy brownish red fumes of nitric peroxide, which are injurious to health.

Bunsen's Battery.—The thinness of the platinum plates in the battery just described renders them liable to fracture; and their high price is also another objection to their general use. M. Bunsen, therefore, sub-

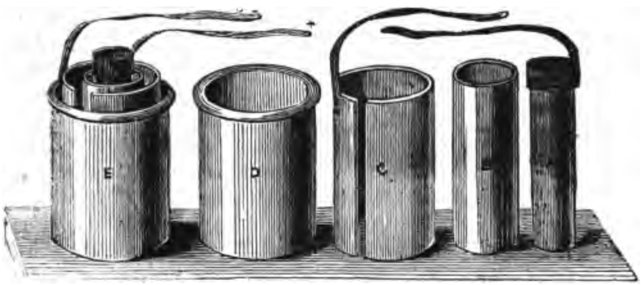


Fig. 34.

stituted for the platinum plates hollow cylinders of carbon, baked in iron moulds, by making coke, reduced to a fine powder, cohesive with molasses. The battery thus made has the cylindrical form of Daniell's battery, from which it differs only in having the hollow cylinder of copper replaced with a hollow cylinder of carbon; pure or dilute nitric acid is used instead of the sulphate of copper solution; and porous cylinders of earthenware must be substituted for animal membrane.

The above figure (34) shows the several parts of one of the cells of a Bunsen's battery, in which, however, it will be observed that the zinc is now the outer, and the carbon the inner element. This is done to enable the zinc to take up oxygen more readily by increasing the surface presented to it.

A is the carbon cylinder. Each of these cylinders is furnished at the upper end with a copper ring carrying a band for connection, which is put in contact with a similar band carried from each zinc cylinder, and secured by clamps. The copper ring should rise sufficiently above the glass vessel, so as not to touch the nitric acid; but with every precaution a portion will rise through the pores of the charcoal and corrode the interior of the copper ring, and this should be well washed and cleaned every time the battery is used. B is the porous cell; C, the cylinder of amalgamated zinc that surrounds the porous cell; D, the external glass or earthenware jar. E represents the entire arrangement of the cell.

Instead of coke cylinders made by Bunsen's process, the hard carbonaceous scales found in the interior of gas retorts may be used with advantage; they may be sawn either into plates or bars with a piece of sheet iron and a little fine sharp sand and water, and can then be rubbed down upon a flat stone of frit to any required shape. These can then be used in every situation where platinum would otherwise be required. The power of these carbon plates is greatly increased by platinizing them as mentioned under Smee's battery.

There are yet some other forms of batteries, which are modifications either of the nitric acid or sulphate of copper batteries, which deserve notice.

Professor Callen, of Maynooth College, found that cast-iron was unassailable by nitric acid, and he therefore employed it as a negative metal in the following simple manner.

He had small iron boxes cast in the shape of parallelopipeds; these were for holding the nitric acid. Into each of these cast-iron boxes or cells was placed

a flat porous diaphragm, as much smaller than the cast-iron box as would allow of the employment of a sufficient quantity of nitric acid. This diaphragm contained an amalgamated zinc plate in a mixture of dilute sulphuric acid, in the proportions of one of water to six of acid. This battery is not at all inferior to Grove's nitric acid battery with platinum plates, whilst its cost is considerably less.

Grove's Gas Battery.—By decomposing water in the tubes, H and O, we obtain the gases hydrogen and oxygen, H at the negative pole, O at the positive pole. Into the tubes are inserted platinum plates with wires. These wires will form the electrodes of the gas battery, H being the positive pole, and O the negative pole; when the circuit is closed, the two gases will gradually disappear, and an electric current will flow.

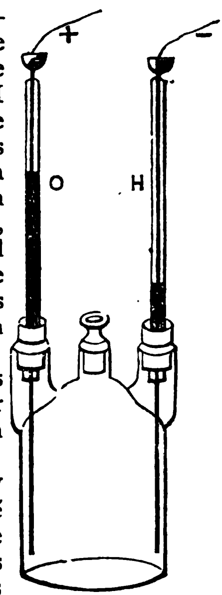


Fig. 35

Walker's Battery resembles Smee's, except that the silver plate is replaced by a carbon plate or platinized carbon.

The Sulphate of Mercury Battery, constructed by Marié Davy, is of small size. In the outer vessel water or brine is placed; and in the inner porous vessel sulphate of mercury in water. The action is readily understood from a consideration of that in Daniell's battery. The plates are zinc and carbon.

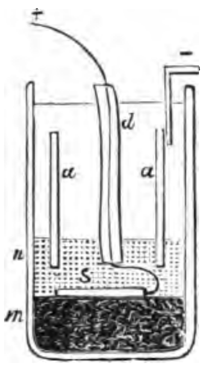


Fig. 36.

Gravity Batteries.—These have been devised to obviate the necessity of using porous cells, which soon get out of order. The separation of the substances is made by the greater density of the one, which consequently keeps the lower place in which the copper plate is immersed. *Fig.* 36 illustrates this battery. It is essentially a Daniell's. *m* is the denser solution, in which is the plate of copper, *s*; *n* and the space above, in which is the cylinder of zinc, *a a*, is occupied by the less dense liquid; *d* is the positive electrode, which is insulated by gutta-percha.

Fig. 37.

Becquerel's Oxygen Circuit.—This is a battery with two liquids, an alkali and an acid, and only one metal, platinum. In *Fig.* 37, P D are plates of platinum connected by a wire. The tube, A B, contains caustic potash, and the end, B, is closed by having a piece of linen tied over it, to which is attached a piece of clay, $\frac{1}{4}$ inch thick. The acid and the alkali act on each other through this, setting up a current which is conducted by the platinum plates, and setting free oxygen in the upper part of the tube. One of these batteries is sufficient to decompose water.

Comparative power of batteries:—

Smee's,	210.
Daniell's,	470.
Grove's,	829.
Bunsen's,	839.

Electrical Relations of Metals.—When any two metals of different characters are immersed in a fluid capable of acting upon one or both, the metal least acted upon is always positive to the other, sending a current through the conducting wire to it. The greater the difference between the relative attractions of the metals for the fluid in which they are immersed, the greater is the electro-motive force of the current developed. In the following list, in which dilute acid is supposed to be the fluid menstruum, if any two metals be immersed at the same time and connected by a conducting wire, the current will pass through the wire from those lower in the list to those higher. Thus all the intermediate metals are both positive and negative; positive to those above because sending forward a current to them through the circuit, and negative to those below because receiving a current from them. Iron, for example, is positive to zinc, but it is negative to copper.

The principal metals forming this voltaic series are as follow:—

Zinc	Nickel	Silver
Cadmium	Bismuth	Gold
Tin	Antimony	Platinum
Lead	Copper	Graphite
Iron		

The greater the distance between any of these metals in the series, the greater will be the energy or

electro-motive force of the current developed between them when immersed. Graphite and zinc, forming the two extremities, produce the strongest current, whilst that excited between any two adjoining metals is comparatively feeble.

Poggendorf states that the electro-motive force produced between any two metals in the series is equal to the sum of the effects of all the immediate combinations.

When the extremities or poles of a battery are examined with an electrometer they are found to be positive or negative, two gold leaves repelling each other at the same pole, and attracting each other at different poles, even when a small space of air intervenes. Hence frictional electricity differs from voltaic electricity in having a much greater elastic force, or a much higher intensity. Voltaic electricity differs from frictional electricity in the great quantity of electricity which is developed and put in motion, and in the continuity or perpetual reproduction of the current. Dr. Faraday has said that the chemical action of a grain of water upon four grains of zinc can evolve electricity equal in quantity to that of a powerful thunderstorm, and that the quantity of electricity in 25¼ grains of water is equal to above 24,000,000 charges of an electrical battery, charged each time with 30 turns of a large and powerful plate machine in full action.

When a battery is in a state of activity, and wires of different metals are introduced between the poles so as to complete the circuit, the current passes through the interposed metals with different degrees of resistance; and the same occurs with reference to the conducting power of water holding in solution different acids, alkalies, or salts. The conducting

power increases according to the quantity of salts dissolved, but more slowly when the solution is nearly saturated.

The Tension of a Battery may be regarded as the tendency of the accumulated electricity to free itself, and overcome the resistances offered by the bodies through which it is conducted. The *tension* of a battery depends on the number of couples, while the *quantity* depends, other things being the same, on the surface of the plates. The larger the surface the greater is the quantity of electricity which flows through the circuit. When about to perform experiments with battery power, it is necessary to consider whether intensity or quantity is required; if the former, the positive and negative plates must be connected in couples, as Zn Pt, Zn Pt, &c. If, on the contrary, quantity is desired, then connect all the zinc plates together to form one large zinc, and all the coppers to make one copper plate. Of course the battery may be arranged also in a modified form, to obtain both results partially. In most cases the tension at the extremities of a battery is far weaker than in electrical machines (except when a large number of couples is employed). Neither of the extremities of a battery will give a spark or attract light bodies, and it is only by a delicate condensing gold-leaf electroscope that the tension can be indicated. In this experiment one of the plates of the electroscope must be connected with one end of the battery, and the other with the earth. The battery is put into action, and on breaking the communication the leaves diverge. A Leyden jar may be charged by connecting the interior coating with one end of the battery, and the external coating with the other, but the charge is always feeble.

Intensity and Direction of Currents.—The

two electricities, when liberated by the chemical action of a battery, tend to reunite and form a neutral fluid. The quantity of electricity which remains free constitutes the tension of the battery or the intensity of the current. When the two extremities of the battery are united by a metallic arc, the tension at first diminishes, but this diminution becomes slower and slower till it reaches its limit, beyond which the tension no longer decreases.

The direction and intensity of a current will depend on the degree of chemical action exerted by the liquid on the metal most liable to oxidation. When the liquid and the metals are known, the direction of the current can be inferred. The metal most acted upon by the liquid takes from the liquid negative electricity. Zinc is more attacked by an acid solution than copper, and therefore takes from the solution its negative electricity; but if we have a solution of sulphide of potassium, which affects the copper more than the zinc, then the order will be reversed; the copper will take negative electricity from the solution, and the current will have an opposite direction. In a battery of zinc and copper plates with an acid solution, the zinc extremity will give negative electricity; in a battery of the same kind with a solution of sulphide of potassium, it will give positive electricity.

Dry Piles.—Whilst some philosophers contended the chemical action was the true source of electricity in the voltaic pile or battery, others maintained that it was derived from the simple contact of dissimilar metals. With this latter view De Luc constructed the instrument which is named after him, De Luc's electric column. It is in principle identical with that of the voltaic pile, with the exception that instead of using cloth moistened with acid or salt, dry

paper alone is used between the couples. As there is no wear and tear by solution or oxidation, and as contiguous surfaces alone are required, the plates may be made infinitely thin, and the following is therefore the construction. Zinc is rolled out into the thinnest foil, made quite clean on its surface, and then punched into discs from ½ to ¾ inch in diameter; a corresponding number of discs are also punched from writing-paper, silvered on one side only. Hundreds or thousands of these discs of zinc and silvered paper are alternated with each other, commencing with zinc, upon which is placed the paper disc with its silvered side downwards in contact with the zinc; then another piece of zinc on the paper and the silvered face upon that again; so that a pile is thus constructed consisting of zinc, silver, paper; zinc, silver, paper; &c.

For convenience these are piled in glass tubes in quantities of from 500 to 600 couples in each. The tubes are furnished at the ends with brass caps, through which small screwed wires pass for the purpose of pressing the discs well into contact with each other. With such a pile the following phenomena are observed:—If held in the hand by one brass cap, the other will attract a feather or a pith ball suspended on a delicate thread, or if placed in contact with the cap of a gold leaf electroscope, it will cause the leaves to diverge. The zinc end will produce positive and the paper end negative electricity. Here is observed the same anomaly as in the voltaic pile. The fact is, electricity is not excited between the faces of the metals which are in contact, but between the surfaces which are separated by the paper. The touching metal surfaces simply serve to conduct from one to another the electricity which has been taken up from the paper. The lower zinc plate then in contact with

the silver surface is useless and can be discarded, as it only indicates the electrical state of the silver plate. This end will be the true silver end, and not the zinc end. In like manner the end terminated by paper is deficient, and requires a zinc plate to complete the couple, as it is called, of silver, paper, and zinc, and this is the true zinc end, yielding the negative electricity, whilst the other, the true silver end, is positive.

The statical or tension effects of this pile are extraordinary, whilst the chemical effects are most insignificant. When an extensive series is required, several of these columns are joined end to end, the positive of one to the negative of the other, the whole being well insulated. A series of 2,000 being so arranged that the first and last ends shall be within three inches of each other, will cause a silvered pith ball suspended by a long thread of silk to vibrate as a carrier of electricity from one to the other, for months or even years; indeed, it is difficult to fix a limit to the duration of their action.

Zamboni modified De Luc's column by substituting binoxide of manganese for zinc, which he slightly moistened and rubbed on to the paper with a cork; it is, however, usually laid on by mixing it into a paste with starch, and laying it on the opposite side of the silvered paper. Tinfoil may be also substituted for the silver, and the instrument is just as effective. A series of 50,000 of these alternations will give sparks a quarter of an inch long, and charge small Leyden phials. A certain hygrometric condition, however, is required in the paper for the perfection of the instrument, for if the discs be thoroughly dried so as to render the paper insulating, the electrical effects are not produced.

Bohnenberger's Qualitative Electroscope.—A most ingenious application of the dry pile for the purpose of increasing the delicacy of the electroscope, while at the same time it rendered it capable of indicating at once the quality of the electricity of any excited body brought near to it, was contrived by Bohnenberger. From an insulated metal cap a wire stem leads into the interior of a suitable glass receiver, and from the end of this stem hangs a single slip of gold-leaf. A dry pile is mounted, so that an insulated wire from each pole, terminating in a ball, passes into the interior of the receiver.

These balls, which are of course always in opposite states of electricity, are placed one on either side of the lower end of the gold-leaf, just so far from it as not to be able to attract it. The substance whose electricity is to be examined is brought near the cap of the instrument, when the gold-leaf instantly becomes similarly electrified by induction, and attracts itself to one or other of the two balls: the one to which it is attracted indicates that the electrical state of the excited body is opposite to its own, since oppositely electrified bodies attract each other, and the electrical state of the balls being known, that of the excited body is at once determined.

Chemical Effects.—When a compound liquid is made to form part of the circuit of a voltaic battery by being introduced between its electrodes, its elements are separated from each other, the one being drawn to the positive, the other to the negative pole. This fact was first noticed in 1800 by Carlisle and Nicholson, who discovered that water was capable of being resolved into its elements when submitted to the action of the terminal platinum or gold wires of a voltaic battery.

Four or five elements of Bunsen's or Grove's form of the nitric acid battery, or a dozen Smee's batteries, are sufficient to decompose water with great rapidity. A very convenient form of apparatus for this purpose is represented in *Fig.* 38.

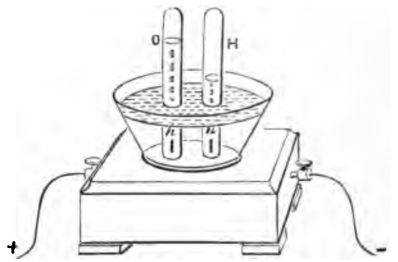


Fig. 38.

It consists of a glass vessel fixed on a wooden base. In the bottom of the vessel two platinum electrodes, *p* and *n*, are fitted, communicating by means of copper wires with the binding screws. The vessel is filled with water to which some sulphuric acid has been added to increase its conductibility, for pure water is an imperfect conductor; two glass tubes filled with water are inverted over the electrodes, and on interposing the apparatus in the circuit a decomposition is rapidly set up, and gas bubbles rise from the surface of each pole. The volume of gas liberated at the negative pole is about double that at the positive, and on examination the former gas is found to be hydrogen and the latter gas oxygen. This experiment accordingly gives at once the qualitative and quantitative analysis of water.

Fig. 39 is an illustration of Faraday's electrolytic

apparatus, which, although rather more expensive, still is valuable; it gives little or no trouble, and not only water but also other compounds in solution, as well as acids, may be decomposed by the electric current, and the elements of which they are built up may be examined. *a a* are the platinum plates to which the battery of four or five Bunsen's is attached by wires. *m n* are the tubes in which the elements of the decomposed compound appear, while by means of the cocks and nozzles above, the gases may be liberated and tested,—hydrogen by its flame; oxygen by relighting a smouldering match; iodine by its effect on starch paper; sulphuretted hydrogen turns lead paper black, &c. The solution is poured in at B, and when kept sufficiently high in the long limb, the instrument acts by pneumatic pressure to expel the gases from tubes *m* and *n*. Make a solution of KI, potassic iodide, in which dissolve a little starch; fill the whole of the tubes, close the circuit; the iodine, of a beautiful blue colour, will appear in one tube, and the potassium, as an insoluble salt, in the other. Again, fill the tubes with HCl, hydrochloric acid, close the circuit. Hydrogen gas will be formed in one tube, which may be tested by its flame, and chlorine gas in the other, which may be tested by its effect on the organs of respiration. The hydrogen gas, if allowed to burn

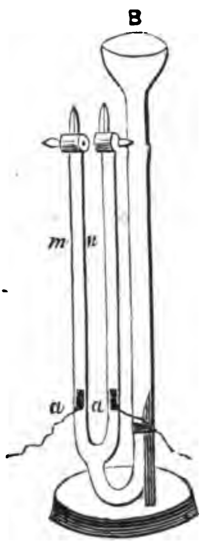


Fig. 39.

above a few seconds, will probably melt the glass, because of the intense heat of hydrogen when inflamed. It is also necessary to be cautious with chlorine gas, as breathing it in a pure state,—that is, without admixture with common air—is certain death. Smelling at the gas three or four inches from the tube will be quite sufficient for the test.

There is another reason for using sulphuric acid in this experiment, the decomposition of water, or rather, there are other considerations which must not be omitted. When water alone is used the action is exceedingly feeble, and a very large number of batteries must be used to obtain an appreciable result. When sulphuric acid is added, it is probable that that also is decomposed by the current, or that the presence of sulphuric anhydride assists chemically in the decomposition of the water. If decomposed, then, H_2SO_4 becomes H_2 and SO_4, and the latter is transferred to the same electrode as the oxygen; but in its course it also decomposes the water, taking up the hydrogen in the neighbourhood of the positive electrode, and liberating the oxygen; and inasmuch as it liberates H_2 at the negative pole, and O at the positive, the quantity remains the same as if the water only were decomposed.

The same remarks apply to the action of batteries, and the student will, no doubt, notice there that when H_2 passes off, $ZnSO_4$ is eventually formed—that is, the SO_4 molecule combines with the Zn atom eventually.

Electrolysis is the decomposition of bodies by means of a voltaic current. The positive electrode is called the *anode*, and the negative the *cathode*. Bodies regarded as simple have been decomposed by means of powerful batteries. Davy proved that

soda and potass were the oxides of unknown metals, sodium and potassium. The decomposition of binary compounds is analogous to that of water; one element goes to the positive and the other to the negative pole. The bodies which go to the positive pole, are called *electro-negative* elements, because at the moment of isolation they are considered as charged with negative electricity; while those separated at the negative pole are for a similar reason called *electro-positive* elements, or more commonly they are spoken of as negative and positive substances.

Laws of electrolysis :—

1. *Electrolysis cannot take place unless the electrolyte is a conductor.*

2. *The same electric current decomposes chemically equivalent quantities of all the bodies which it traverses.*

3. *The quantity decomposed in a given time is proportional to the intensity of the current.*

Decomposition of Sulphate of Potass (K_2SO_4).—The decomposition of salts may also be shown with a U glass tube. This tube is nearly filled with a saturated solution of a soda salt, coloured with blue cabbage or tincture of violets. The platinum electrodes of about four of Bunsen's elements are then placed in the two limbs of the bent tube. In a few minutes the liquid in the positive limb becomes red, and in the negative limb green. This shows that the salt has been decomposed into an acid, which has gone to the positive pole, and a base, which has gone to the negative pole, and these colours are precisely what are obtained by the action of a free acid and a base on paper stained with blue cabbage or tincture of violets. In a solution of sulphate of copper ($CuSO_4$) the acid and oxygen gas appear at the positive electrode, and metallic copper at the negative

electrode; and similarly nitrate of silver ($AgNO_3$)—the silver goes to the negative and the acid and oxygen to the positive electrode. This decomposition is generally expressed by saying the acid is liberated at the positive electrode and the base at the negative.

In chemical depositions effected by this current there is not only a passage of the electricity through the liquid, but a positive transference of the solid particles held in solution after the original solid particles have been decomposed. Davy demonstrated this in the following manner: he placed a solution of sulphate of soda in two small vessels, which he connected by a thread of asbestos, through which the liquids flowed by capillarity. After the current had run through the vessels and asbestos for some time, he tested, and found that all the soda was in one vessel and all the sulphuric acid in the other. By a second experiment this transmission of particles is still more clearly shown.

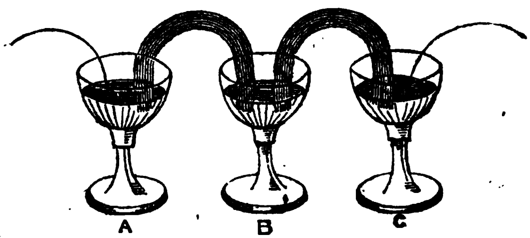


Fig. 40.

Fig. 40. Here we have three vessels, A, B, and C, connected by threads of asbestos, or by bent tubes of glass filled with water. In A put a solution of argentic nitrate ($AgNO_3$), in B a solution of soda chloride ($NaCl$), and in C a solution of baric sulphate

($BaSO_4$). Then put the positive electrode in C and the negative in A. With the passage of the current the following will be the result:—

$AgNO_3$	$NaCl$	$BaSO_4$
A	B	C

In A the atom of silver will be evolved at the platinum plate, and in C the atom of sulphuric acid is evolved at the platinum electrode; also the NO_3 of A has passed over to B, and the Cl of B to the Ba of C; so that they stand now as—

Ag $NaNO_3$ $BaCl_2$ SO_4

Electro-plating.—The decomposition of salts by a battery has been applied to the art of precipitating metals from their solutions by the slow action of a voltaic current.

To take a copper cast, a bath is filled with a saturated solution of sulphate of copper (*Fig.* 41).

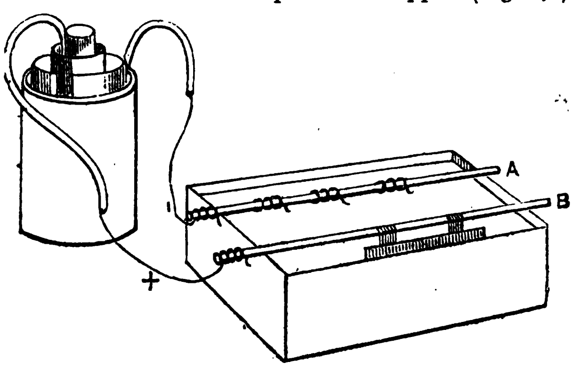


Fig. 41.

Two brass rods pass across and rest on the ends of the bath. One of these rods is connected with the positive and the other with the negative pole of a Daniell's

element. From the rod, A, connected with the negative pole is suspended the mould, and from the rod, B, a plate of copper. The current is now closed, the salt is decomposed, the acid is liberated at the positive pole, while copper is deposited on the negative mould. If the bath be large enough, several moulds may be suspended at the same time. In about forty-eight hours, the mould is covered with a solid layer of copper which can be easily detached from the mould. If the cast be taken from plaster, which is usually the case, it must first be immersed in a bath of melted wax, and quickly withdrawn. The rapid drying of the wax after withdrawal arises from the absorption of stearine by the plaster. When cooled it is coated carefully and thoroughly with graphite, or black-lead, by means of a soft camel's-hair pencil. A strip of cartridge-paper is then passed round the edge, and some melted stearine is poured upon it; on cooling, this gives a hollow cast of the original metal. This is prevented from adhering to the plaster by the black-lead. It is then removed and covered with black-lead, to present a conducting surface. The mould so prepared is suspended from the negative pole of the battery. Very good moulds may be obtained with gutta-percha, which are prepared in a similar manner. The copper plate suspended in the bath not only closes the circuit, but keeps the solution in a state of concentration; for, as the solution loses its metal, the acid liberated attacks the metalic plate, reviving the strength of the solution.

Electro-gilding was formerly done by means of an amalgam of gold and mercury, applied on the metal to be gilded, which was afterwards heated in a furnace sufficiently to volatilize the mercury. The work was most unhealthy and expensive, and it has been entirely superseded by electro-gilding and

electro-silvering. The objects to be gilded or silvered are first heated, so as to remove all the fatty matter which has adhered in previous processes. As the objects to be gilded are usually copper, the surface in heating becomes covered with a film of the protoxide of copper. This is removed by another process. The object, while still hot, is immersed in a bath of dilute nitric acid, to remove the oxide. It is then rubbed with a hard brush, washed in distilled water, and carefully dried in heated wood shavings. To remove any spots which appear, the object is rapidly immersed in ordinary nitric acid, and then in a bath which consists of a mixture of nitric acid, bay salt, and soot. When the object has been so prepared, it is attached to the negative pole of a battery consisting of three or four elements of a Bunsen's or a Daniell's, and immersed in a bath which consists of 1 grain of chloride of gold, 10 grains of cyanide of potassium, dissolved in 200 grains of water. This mixture varies with different firms. To keep the solution concentrated a piece of gold is suspended from the positive electrode. This method will gild copper, silver, bronze, brass, and nickel. Iron, tin, zinc, lead, and steel, are difficult to gild. To obtain a good coating on these metals they are first covered with copper.

Electro-silvering is exactly similar, except in the composition of the bath, which usually consists of two parts of cyanide of silver and two parts of cyanide of potassium, dissolved in 250 grains of water.

Polarization and Transfer of the Elements of the Liquid.—Powerful chemical action is not alone sufficient to produce a powerful voltaic effect. All the metals are good conductors of electricity, and when they combine to form alloys they often give evidence of intense chemical action; but the voltaic

effect is often very small. If a glass tube in the form of a U be taken, and a small quantity of tin melted by means of a spirit lamp; and if the wire of a galvanometer be introduced down one limb of the tube into the melted tin, while in the other limb of the tube the platinum wire connected with the other extremity of the galvanometer be introduced, the platinum will unite with the tin; but after the first instant of contact no permanent deviation of the needle will be observed, although the chemical action continues for some time. In order that the liquid shall have the power of exciting voltaic action, it must be a liquid capable of decomposition by one of the metals. The necessity of a compound liquid for exciting the force appears to arise from the necessity of peculiar polarization in the liquid in order to transmit voltaic action. In all voltaic actions the transfer of power is effected by a polar influence propagated through the liquid and solid particles of the circuit, and the chain of the conducting material must be continuous throughout, so that the force may circulate. This process of polarization may be conceived to occur in the following manner, which offers an explanation of the manner in which the platinum, or other metal analogous to it, may be supposed to act:—

When a plate of pure zinc or of amalgamated zinc is immersed in a compound liquid which is capable of attracting it chemically, the metal at the points of contact becomes positively electrified, whilst the distant portion becomes negative. The layer of liquid in contact with the zinc undergoes polarization, which affects each molecule of its chemical constituents. If dilute hydrochloric acid (HCl) be used, the particles of chlorine become negative, and the particles of hydrogen positive; but in this condition there is no

communication between the negative particles and the positively electrified particles of hydrogen; consequently, beyond the production of this state of electrical tension, no change takes place. This condition may be represented by *Fig.* 42 (1).

But the condition is entirely altered if a plate of platinum be introduced, or some metal not so easily acted on by the acid, and made to touch the zinc. By contact with the zinc the platinum becomes polarized; it imparts a portion of positive electricity to the zinc, and receives a portion of negative electricity in return, and transmits the polar action to the liquid. A chain of polarized particles is thus produced, as in (1). The chlorine of the particle of HCl nearest the zinc becomes negative, under the influence of the chemical affinity which exists between it and the zinc, and the

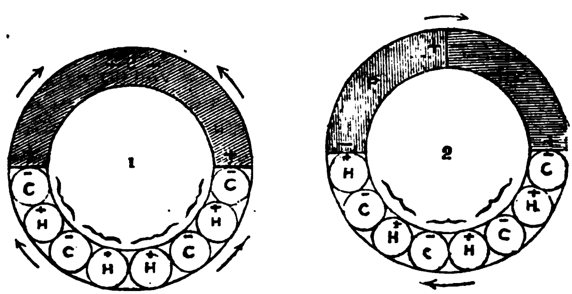


Fig. 42.

hydrogen becomes positive. The second and third particles of the acid become similarly electrified by induction; but the platinum, under the influence of the induction of the zinc, being negative, is in a condition to take up the positive electricity of the contiguous

hydrogen (2). The action now rises high enough to enable the zinc and the chlorine to combine chemically, forming chloride of zinc, which is dissolved by the liquid and removed from further action; but the particle of hydrogen nearest the zinc now seizes the oppositely electrified particle of chlorine which lies next to it, and a new portion of HCl is reproduced, whilst the hydrogen in the second particle of the acid is transferred to the chlorine of the contiguous particle, and the particle of hydrogen which terminates the rim is electrically neutralized by its action upon the platinum, to which it imparts its excess of positive electricity, and immediately escapes in the form of gas. Fresh particles supply the place of those which have been decomposed; and in this way a continuous action is kept up. The transfer of electricity from particle to particle of the liquid is attended with a transfer of the constituents of the liquid in opposite directions. These changes, when continued uninterruptedly, constitute what is called a voltaic current; but this word current is merely a convenient expression. In every voltaic current it is assumed that a quantity of negative electricity equal in amount to that of the positive is set in motion, and proceeds along the conducting medium, or wire, in a direction opposite to that in which the positive is moving; and it is supposed that by the continual separation and recombination of the two electricities in the wire its heating and other effects are produced. In order to avoid confusion, when the direction of a current is mentioned, the direction of the positive current is alone indicated.

It will be well here to review the steps taken, so as to obtain a clear idea of what takes place in a circuit. The term current, we have said, is only used for con-

venience, as we will now endeavour to show by means of *Fig.* 43.

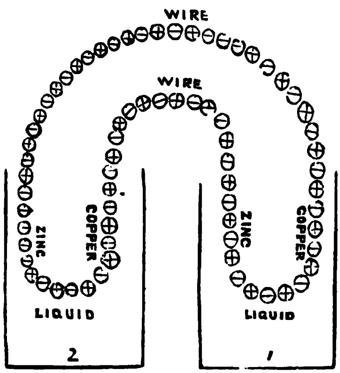


Fig. 43.

On the insertion of the first couple Zn + Cu in vessel No. 1, and on connection of the wires from the two plates outside the liquid, the following is supposed to take place. The atoms of zinc decompose the molecules of water, separating H and O, one of which is positively, the other negatively electrified. The nearest atom of O combines with the zinc, its H thrown off combines with the next atom of O further towards the copper plate, and this goes on until the last atoms of H are thrown to the copper, and come off there, having no O or other element with which they can combine. Suppose atoms of zinc in the liquid to be positive, then oxygen atoms will be negative, hydrogen atoms positive; and if we go further, and suppose copper plates and wires to be made up of atoms which are successively positive and negative, as in the figure,

we then got a good idea of what is meant by the polarization of the whole circuit. Now if a Zn atom combines with an O atom, the chain is broken, the inductive series will fall away instantly, and will be as rapidly reproduced by the chemical affinity of the Zn and O. This constant charging and discharging succeed each other so rapidly that the effect of a continuous stream of electricity is noticed,—hence the term current.

Polarization of the Circuit.—The foregoing remarks have referred principally to the polarization of the particles of the liquid transmitting the voltaic current.

Referring for a moment to the change of colour produced in the legs of the U-shaped tube by the action of the electrodes, namely, the production of a red colour in one leg and green in the other, it will be seen that one half of the liquid has been brought under the influence of the current into a negative, and the other into a positive condition, the two electrodes themselves producing the influence in virtue of their opposite electrical characters.

It has been before stated that if a metallic circuit be interrupted in any part, the terminals thus formed instantly exhibit opposite electrical states, the one being anode and the other cathode. And if it were possible to divide a metallic circuit into twenty parts, without intercepting the flow of the current, every piece of the disjointed wire would be positive at one end and negative at the other; and these ends would thus produce the chemical effects due to the terminals proper of the battery. This is beautifully shown in the following experiment:—

Take three U-shaped tubes, *a b*, *c d*, *e f* (*Fig.* 44), and fix them upon a wooden stand so that they shall all be in the same line; now fill them with a saline

solution, say common salt, coloured blue with blue cabbage, and insert the anode and cathode of the battery in the two extreme legs of the series, *a* and *f*.

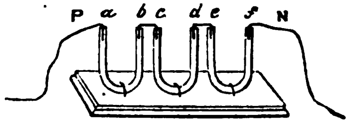


Fig. 44.

If now the tubes be connected with each other by bent wire or slips of platinum-foil, we have a compound circuit consisting of alternations of good and bad conductors.

According to the law already stated, each of the connecting wires will have an anode at one end and a cathode at the other, so that each tube of liquid will thus have one of its legs rendered positive and the other negative; and these will appear red and green alternately throughout the series. If the connection with the electrodes be reversed the colours will also be reversed.

This experiment may be varied in the following manner. Substitute a solution of acetate of lead for the blue infusion of cabbage in the tubes, and connect them with each other by means of slips of platinum-foil, the electrodes of the battery being also of platinum. In a short time the negative terminal of the battery, as well as the two negative terminals of the connecting metallic slips, will begin to revive metallic lead from the solution; this will exhibit itself in a beautiful crystalline vegetation, resembling small fern leaves, which will extend in an arborescent form down the tubes, to a greater or less distance, according to the length of time the battery is kept in action. Whilst

the negative electrodes are thus attracting the metal the corresponding positive electrodes are liberating oxygen gas with rapid effervescence.

The rapidity with which any of the foregoing actions take place depends upon the quantity of electricity flowing through the circuit in a given time. This flow is modified and controlled by a variety of circumstances, such as the resistance offered by the nature of the circuit itself, and the variable electro-motive power of the battery.

The best arrangements do not develop the whole of the force which results from chemical decomposition. The causes which obstruct the development of electricity in a current have been investigated by Professor Ohm, who has reduced them to a mathematical formula. (*See articles on Ohm's Formula.*) The free development of electricity is resisted by the affinity of the elements of the liquid, which tends to resist decomposition, the imperfect conduction of the fluid, and the resistance of the conducting wire or other circuit.

Thermal Influence. — We have already mentioned the evolution of heat. Now the same effect is also produced when a voltaic current is passed through a metallic wire. A very powerful battery will melt thin wires of the most infusible metals, and rods of pure carbon have been so raised in temperature as to be softened and welded together. In mining operations a small wooden cartridge containing powder is covered, in some convenient position in the mine, with powder. In this wooden cartridge two thick insulated wires are inserted, and joined in the interior with a fine iron wire. Two long wires lead to the terminals of a battery of sufficient strength. When the circuit is complete, the fine iron wire becomes incan-

descent, and the powder in the mine explodes. In fine wires the thermal effect is most easily seen, but thicker wires are similarly influenced. By an instrument termed the thermo-electrometer or galvano-thermometer, the thermal effect of electric currents has been established as follows :—

1. The heat disengaged is directly proportional to the square of the intensity of the current and to the resistance of the wire.

2. Whatever be the length of the wire, if the diameter remain the same, and the same quantity of electricity passes, the increase of temperature is the same in all parts of the wire.

3. For the same quantity of electricity the increase of temperature in different parts of the wire is inversely as the fourth power of the diameter.

If wires of the same size, but of different metals, such as platinum, iron, and silver, be interposed in the voltaic circuit, the platinum becomes most heated, because of its greater resistance. A number of interesting experiments may be shown by the teacher in illustration of this part of the subject.

Mr. Hearder, in the course of his experiments with the thermo-electrometer, observed an apparent exception to those laws; for on employing a battery consisting of a single pair of plates of very large surface, a wire, say of platinum, of a given size, is inserted in the bulb of a thermo-electrometer, hereafter described, and the current from a Smee's battery, containing say, six square inches of silver surface, is caused to pass through it. The fluid in the tube rises, say, 10°,

A second similar battery is now added for quantity, like plates being joined to each other; the fluid still marks 10°, showing that no increase of electro-motive

force has been obtained in the battery. A third, fourth, fifth, and sixth battery may now be added, without the slightest increase of temperature being indicated by the thermo-electrometer.

Let the experiment now be varied by adding these batteries to each other in series, so as to increase the electro-motive intensity, and it will now be found that each additional battery carries its own effect into the wire, the resistance of which is constant, and the heat produced is therefore exactly equal to the increments of the intensity in the battery; for the fluid in the tube of the instrument will rise 10° with the addition of each successive element, and these effects are beautifully uniform if the slight increase of resistance in the wire as the result of increased temperature be allowed for.

That metal wires have their conducting capacity diminished by raising their temperature is best shown by the following experiment. Let two thermo-electrometers be connected with each other so that the current from a battery passes consecutively through them both; thus each serves to control the current passing to the other. The fluid in the tube of each electrometer will indicate a certain temperature. Whilst matters are in this state, let the terminals of a second battery be applied to one of the electrometers, so as to pass an additional current through it. The temperature of the wire in the interior will immediately be raised, as will be seen by the rise of the fluid in the tube, but its conducting power will at the same time be diminished, so as to cause it to intercept a portion of the current previously passing through the second instrument, the wire of which will be reduced in temperature, and the fluid in the tube will fall, whilst that in the other is rising. On disconnecting

the second battery the two instruments mark their original temperatures.

The converse of this experiment, namely, the increase of conducting power in a wire by the reduction of its temperature, may be shown by the following experiment :—

Take ten or twelve inches of fine platinum wire, attach it to the ends of two stout copper wires, so that the centre of it may hang down in a long loop in the form of the letter U ; pass through it a current from a battery of three or four Grove's cells, or eight or ten Smee's, by connecting the terminals with the stout wires. The platinum wire will now be ignited to a red heat. Whilst in this condition bring up under it a vessel of water, so that a portion of the ignited loop may dip into it ; this has the effect of cooling the portion immersed, and thereby increasing its conducting power, and a larger quantity flows therefore in a given time through the two portions which are out of the water, thereby increasing their temperature. As the water is raised so as to immerse more of the loop, the temperature of the ignited portions can be increased to whiteness, or even to the melting point, and this increase and diminution of effect follows the raising or depression of the water.

Luminous Property.—Where the circuit of a battery is closed, the point of contact frequently emits a spark of great brilliancy, and a similar result follows on breaking the contact. These effects are only obtained from powerful batteries.

With a battery of thirty or forty Grove's or Bunsen's cells, the following phenomena may be exhibited :—

Bring the copper terminals, which may be one-eighth of an inch thick, in contact with each other, and then separate them to about one-eighth or a quarter

of an inch. A stream of the most vivid green flame will pass with a loud hissing noise between them, melting the ends of the terminals, which fall in globules. Both terminals become red-hot, but the negative one very much more so than the positive. If the terminals be of silver, the green flame is more intense in colour, but not quite so large, and the sound more subdued.

Terminals of steel wire enter into the most vivid combustion, and require a little management to prevent their sudden incorporation with each other by the fusion which takes place at the moment of contact. Lead and tin burn with a greyish white light, and melt down very rapidly. The combustion of zinc is a most vivid experiment; it produces a large flame of varied hue, white, red, and violet being the predominant colours. The combustion of brass wire is interesting and instructive. Where the mixture of copper and zinc is homogeneous, the green light of the one and the pink of the other, being complementary colours, produce a white light, but here and there an excess of copper on the one hand or zinc on the other manifests itself by its characteristic light. Two bars of magnesium, about three-eighths of an inch thick, produce an effect of indescribable brilliancy. The intensity of the combustion increases every moment, until the terminals become ignited through their whole length, and burst into the most dazzling flame.

Dr. Letheby has contrived a most ingenious mode of exhibiting the characteristic colours resulting from the combustion of metals by the electric current.

He prepares terminals by cutting out pencils of coke, which he steeps in solutions of the chloride of the various metals, and then dries them carefully and

preserves them for use. When these form the terminals of a powerful battery the current passing between them is beautifully tinged with different colours, according to the metal employed.

Electric Light.—When two pencils of charcoal form the electrodes, and the terminals are connected with a battery, most brilliant light is obtained. The two charcoal points are first placed in contact; the current soon raises them to incandescence; they are then removed about one-eighth of an inch or more according to the intensity of the current. An arc extends between the points, of exceeding brilliancy; it is called the voltaic arc, and its length varies with the force of the current. One of the charcoal points is fixed, and the other is moved by means of a rack and pinion. When the light is used for the purposes of illumination, the distance between the charcoal points must not alter, and the current must be constant. Without these conditions the light is not continuous. M. Duboscq has invented an apparatus to secure these conditions. The drawback to this apparatus is, that it is costly and soon out of repair without careful use.

Mr. Browning, of the Minories, has contrived an ingenious piece of mechanism for exhibiting the electric light, which is at the same time moderate in cost and simple in management.

In *Fig.* 45 the carbon points are carried by the holders, A B, which are provided with rings like a porte-crayon, to clamp the points when in position. C D is a soft iron feeder; the end, C, of this feeder is so arranged that a very slight pressure on the feeder clamps the rod, B, and prevents it from descending. E is a rod of soft iron, in the form of a horseshoe; when the electricity passes through the wire wound upon this horseshoe, the iron becomes a magnet, and

attracts the feeder. F and G are clamping screws to clamp the sliding rods in any required position. H is

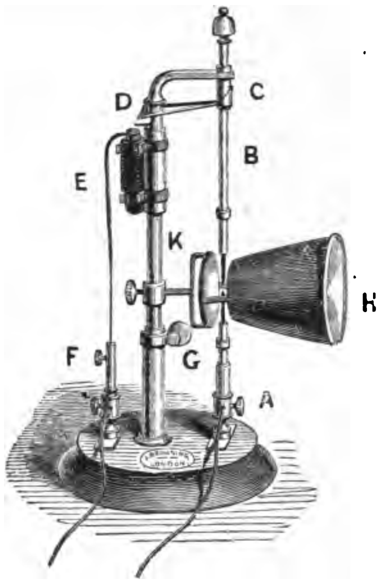


Fig. 45.*

a silvered parabolic reflector for throwing the light of the lamp to a great distance.

To Set the Lamp in Action.—Release the clamps, F G, place two pieces of fine hard carbon in the holders; the carbons should be well pointed; wipe the rod, B, with a leather, so that it may slide freely; then adjust the large central rod, so that the extreme point of the upper carbon rests exactly upon the lower

* I am indebted to Mr. Browning, 111, Minories, for this Diagram.

carbon. Attach the wire from the last plate of zinc in the battery to the lower carbon holder, and the wire from the plate of platinum at the opposite end of the battery to the upper carbon holder. If the light should not burn steadily, alter the position of the magnet by means of a small set-screw between the ends; this screw is not shown in the drawing. The magnet must not be put close to the feeder; the best distance to place the magnet from the feeder is generally about half an inch, but this will vary with the power of the battery employed. When correctly adjusted there should be no perceptible movement of the feeder.

For practical purposes pencils made from the hard coke-scales found in gas retorts will be found to be much more durable than charcoal, and are therefore usually employed for the purposes of the electric light.

As quantity is the great desideratum in the production of the electric light, there is no advantage in increasing the intensity beyond 30 or 40 nitric acid elements: thus if 80 cells are to be used, they are infinitely better arranged in a double set of 40 than in a single series of 80.

Ohm's Law and Formulæ.—By the term *electro-motive force* is meant the force or cause which sets electricity in motion; and by *intensity of current* we mean the quantity of electricity which, in any unit of time, passes through a section of the circuit.

Ohm found that this intensity is the same in all parts of one and the same circuit, however heterogeneous they may be, and also that it is proportional to the electro-motive force. It has also been noticed that when we pass a current through a short and a long wire of the same material, its action on a

magnetic needle is less in the latter case than in the former. Here there is evidently a greater resistance, and the intensity of the current is expended in some degree in overcoming this extra resistance; Ohm proved that this resistance is inversely proportional to the strength of the current.

On these data is founded the following law :—*The intensity of the current is equal to the electro-motive force divided by the resistance.*

$$\text{Formula :—} I = \frac{E}{R}.$$

I. Intensity of current.
E. Electro-motive force.
R. Resistance.

Now resistance depends upon *conductivity*, *section*, and *length*. The less the conducting power, the greater the resistance; therefore resistance is evidently inversely proportional to conductivity. Also, resistance is inversely as the section, and directly as the length, of a conductor; so that *the intensity of a current is inversely proportional to the length of the conductor, and directly proportional to its section and conductivity.*

$$\text{Formula :—} R = \frac{l}{cs}.$$

$$I = \frac{E}{\frac{l}{cs}} = \frac{csE}{l}.$$

c is the conductivity.
s is section.
l is length of the conductor, and the other letters as before.

Two resistances are to be considered: the internal, or that which is offered by the liquid conductor; and the external, which is between the poles of the battery along the conducting wire. Let R represent the internal resistance, and *r* the external, then the first formula becomes—

$$I = \frac{E}{R + r}.$$

Now, in joining together any number of simple elements, *n*, there is *n* times E; but at the same time *n* times R, and we have the formula thus:—

$$I = \frac{nE}{nR} = \frac{E}{R}$$

that is, a battery consisting of several elements produces, in this case, no greater effect than a single element. This would occur where the external resistance was small, as when using a short thick wire to connect the poles. When employing a long thin wire, the intensity is, within certain limits, very nearly proportional to the number of elements.

Again, an increase in the size of the plate, or, what is the same thing, a decrease in the internal resistance, does not increase the intensity to an indefinite extent; ultimately the resistance, R, dwindles in comparison with resistance, *r*, and intensity approximates to the value—

$$I = \frac{E}{r};$$

that is, the intensity is inversely as the length of the conducting wire.

By means of Ohm's law we may arrange a battery so as to obtain the greatest effect in any given case.

For instance, with a battery of six Bunsen's elements we may arrange them Zn to C, Zn to C, &c. (*Fig.* 46),—

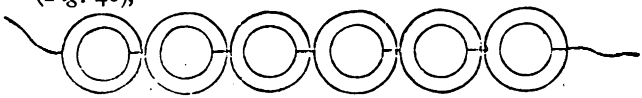


Fig. 46.

or join all the zincs and all the carbons, so as to give one large element (*Fig.* 47),—

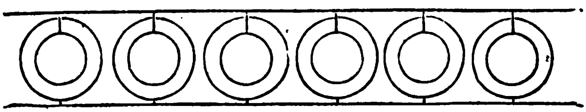


Fig. 47.

In the first case, let us suppose that $R = 3$ and $r = 12$. Then the value—

$$I = \frac{6E}{6R + r} = \frac{6E}{6 \times 3 + 12} = \frac{6E}{30}.$$

When the six elements are combined so as to form one large element (*Fig.* 46), E would then be the electro-motive force in each element; there would also be a resistance, R, in each element, but this would only be one-sixth as great, for the section of the plate is now six times what it was before. Hence intensity would be—

$$I = \frac{E}{\frac{R}{6} + r} = \frac{E}{\frac{3}{6} + 12} = \frac{2E}{25};$$

hence this change would enormously decrease the intensity.

In any given combination the maximum effect is obtained when the total resistance in the elements is equal to the external resistance. Suppose that in a given case n elements are arranged so as to form a battery of s couples, each consisting of t cells, $n = st$. Let r represent the resistance of a single element, then total resistance is $\frac{rs}{t} = l$, when l stands for the external resistance. But $t = \frac{n}{s}$, hence $\frac{rs^2}{n} = l$, or $s = \sqrt{\frac{ln}{r}}$.

MAGNETO-ELECTRICITY AND ELECTRO-MAGNETISM.

As the term electro-magnetism indicates the production of magnetism through the agency of electricity, so the term magneto-electricity implies the development of electricity from magnetic influence. In 1819 Professor Oersted, of Copenhagen, published a work in which he described experiments that suggested a close connection between magnetism and electricity; subsequent experiments and discoveries have confirmed his suggestions; and, indeed, it is not at all difficult, by experiment, to show this close connection.

EXPERIMENT 1.—Place a small magnetic needle in the magnetic meridian, pass the current over it along a copper wire in the direction of its length; the needle will be deflected, and will tend to arrange itself at right angles to the magnetic meridian, and that in proportion to the strength of the current, although as the needle gets more towards the transverse position, much more current strength is required to compel it to move towards completing the right angle, which in reality it never does.

EXP. 2.—Now pass the current under the needle, it will be seen that the needle deflects, but in the opposite direction.

EXP. 3.—Reverse the direction of the current, and the result will be that the needle will vary its direction.

We have throughout assumed that the current flows from the positive to the negative plate, that is, from the platinum to the zinc through the wire circuit, and that we have to do with the north pole only of the needle. The student will do well to remember that—

1. *If the current passes above the needle, and goes from south to north, the north pole of the needle is deflected towards the west.*

2. *If the current passes below the needle, also from south to north, the north pole is deflected towards the east.*

3. *When the current passes above the needle, but from north to south, the north pole is deflected towards the east.*

4. *The deflection is towards the west when the current flows from north to south below the needle.**

To remember the direction of the needle under the influence of a current, Ampère imagines the observer buried in the conducting wire, with the current entering at his feet and passing out at his head, and his face always turned towards the needle. In this position the north pole is always deflected towards the left of the observer. We consider the current to pass from the Cu to the Zn along the conducting wire with a right-handed spiral motion, and suppose it to kick the N. end of the magnetic needle. In this way the following general principle is obtained:—

In the directive action of currents on magnets, the north pole is always deflected towards the left of the current.

* It is already well known that when the magnetic needle assumes a position of rest it will be north and south approximately. Pass the current across the needle while in this position, and the following effects will be noticed:—

Above the needle, W. to E.—No effect beyond slightly raising the N. pole.
E. to W.—The position of the needle is reversed, but the poles are not actually changed.

Below the needle, W. to E.—As in the second case above.
E. to W.—N. pole slightly depressed, no other result.

These four important rules may be presented, perhaps, in a shorter form, as follows:—

Deflection,	west,	current	above	needle,	S. to N.
”	”	”	below	”	N. to S.
”	east	”	above	”	N. to S.
”	”	”	below	”	S. to N.

In EXERCISES will be found examples for a student or a class, and it is important that these and others should be carefully worked out.

Mutual Relation between the Current and the Magnet.—EXP. 4. Over a magnetized needle of some strength arrange the current wire so that the ends of that part of the wire which is over the needle are free to move, or as nearly so as you can get them. Then on passing the current it will be found that the wire will show the same tendency to place itself at right angles to the direction of the current.

By further experiment, however varied, it will be further demonstrated that the relation between the magnet and current is mutual: we shall return to this subject in a later article.

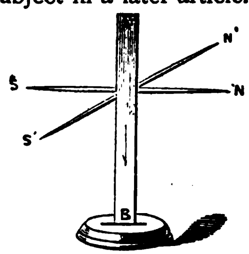


Fig. 48.

Now let A B (*Fig.* 48) be a stout slip of copper, with a magnetized needle suspended behind it, and made to hang, when at rest, in a vertical position, and to be moveable only in a vertical plane. If a galvanic current is made to descend from A to B, the needle will be deflected into the position N′ S′, its north end moving to the

right as you look in front of it. As the force of the current increases the deflection increases, until the needle attains a position nearly at right angles to the current, at which position it will remain, no matter what further force may be given to the current. If the piece of copper was bent round at the bottom in the form of a U, and the current, instead of passing away at B, was carried upward, then the portion of the current ascending would act on the needle just as much as the current descending, so that the whole effect of the two currents is to increase the deflection of the needle, always bearing in mind that the deflection cannot exceed the limit before alluded to.

The Multiplier.—By continuing this process—that is, by causing the current to pass many times about the needle—we increase the effect. This is accomplished by employing a copper wire, insulated with cotton or silk, and making several convolutions on a wooden frame. The length and thickness of the wire of which the multiplier is made will vary according to the uses to which it is applied. A short length of thick wire is used for strong currents, and a very long length of thin wire for feeble currents. A strong current requires to be increased or multiplied fewer times, or to pass fewer times round the needle, than a weak current.

The multiplier has usually a graduated circle, and the deflection gives an idea of the strength of the current, and hence it has been termed a galvanometer. The sensibility of a galvanometer is further increased by placing outside the coil a second magnetic needle of like power, with its poles reversed. The directive force of the earth is then neutralized. A pair of needles so arranged constitute an astatic combination.

The Astatic Galvanometer is represented in *Fig.* 49. The needles, *n s*, *s n*, are suspended, one within the coil and one above it, by means of a fibre of fine silk, the whole being enclosed in a cylindrical glass case. The parallelisms of the needles are secured by connecting them together with a thin piece of copper wire. The fibre of the silk, being attached to the upper extremity of the wire, *d*, by means of a screw at *a*, the point of suspension of the silk can be either raised or depressed without twisting it, so that when the instrument is not in use the silk fibre is relieved of the weight of the needles. *C C* is a circular

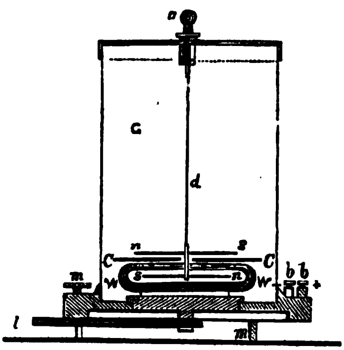


Fig. 49.

piece of copper, graduated on its outer margin, for observing the angular deviation of the needles. *b b* are little cups of mercury for connecting the two extremities of the coil with the wires which transmit the current. The apparatus is levelled by two screws on the under side; and the coil of wire is placed,

by means of a lever, accurately parallel to the two needles, so as make them coincide with the zero of the graduated circle. Such an apparatus will not only indicate the existence of voltaic action, but it will also measure its amount. When the deviations of the needles are small, say 15° or 20°, the number of degrees of deviation gives nearly the exact force, but for larger angles of deviation this is not the case, because the more the needle deviates from the parallelism of the coil, the more obliquely, and therefore the less powerfully, does the force act which occasions the deviation.

On the point just demonstrated depends that most valuable implement, the electric telegraph. The deflection of the needle, of course, will be the same at whatever distance, so long as the conditions are alike, and by the help of the multiplier, the weakest current may be made, without expense or trouble, to deflect the needle and give the desired results.

Electric Telegraph.—The telegraph may be regarded as made up of three parts, viz. :—1, A battery, or some source of electric power; 2, A line for transmitting this power; and 3. An indicator for exhibiting the signals.

The battery may be of any kind; but the form commonly in use in this country for the purpose consists of a series of plates of copper and amalgamated zinc, arranged in wooden troughs, divided into compartments, and coated inside with shellac. After the plates are introduced, the cells are filled with silver sand, and moistened with dilute sulphuric acid.

The conducting wire is made of galvanized iron, about one-third of an inch thick, and supported on wooden posts. At the upper ends of these posts, short porcelain or glass tubes project, around which

the wire passes. If a message has to be sent from London to Liverpool, a continuous insulating conducting wire must extend between the battery in London and the battery in Liverpool, and there must also be a continuous conducting communication between Liverpool and London to complete the circuit. This return conductor may be another wire going from Liverpool to London, and insulated from

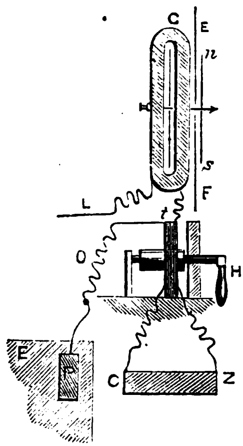


Fig. 50.

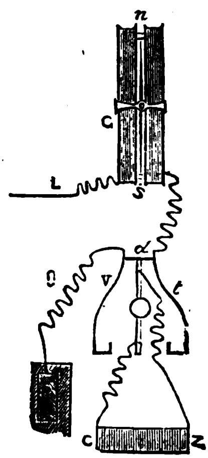


Fig. 51.

the first wire by being suspended through procelain or glass tubes, on the same posts, a sufficient distance from each other. It was discovered by Steinheil that we may dispense with the second wire, and that the earth may be employed as the conductor for completing the circuit, or return communication, between the two distant stations. The possibility of doing this

arises from the law of conduction in solids, viz., that the conducting power increases in proportion to the area of the section of the conductor. In practice all that is necessary to take advantage of the conducting power of the earth is to lead the return wire from the coil to the earth-plate.

The arrangement by which the signals are shown is simply a galvanometer, in which two needles are hung vertically. A section of this part of the apparatus is shown in *Fig.* 50. E F is the dial-plate in section, and *n s* is the indicating needle in front. Behind this, in the coil G, is another needle reversed; that is, the north pole points downwards. The deflections of the needle, *n s*, are limited by little ivory studs in the dial-plate. L and O are the wires which connect the distant station; C Z is the battery; H is the handle by which the instrument is worked; and P, the earth-plate.

Fig. 51 is a back view of the instrument when at rest. A current sent from a distant battery enters the galvanometer by the wire, L, passes round the coil, deflects the needle, and escapes by the right-hand wire, which is connected with a steel spring, *t*; it then passes across the metallic bar, *d*, into a similar spring on the left, V; and the circuit is completed by the wire, O, which is attached to the earth-plate, P; the earth acting as the return wire to the distant battery. The battery, C Z, during this operation, is inactive, because the wires, although connected with the brass ends of the vertical piece, are insulated by a circular piece of ivory in the centre. No current can flow, because the wire proceeding from the end of the battery at C is entirely insulated.

When a signal has to be forwarded to a distant station, the handle, H (*Fig.* 50), is moved either to

the right or left. In *Fig.* 52 it is represented as moved to the left. The cross-piece, *d*, is pressed against one of the metallic springs, as shown in *Fig.* 52 ; and by the same movement the lower end of the vertical piece is pressed against V. The current now flows in the direction indicated by the arrows. The current starts from C to the metallic spring, V, and passes from that to the earth-plate, P ; it then proceeds

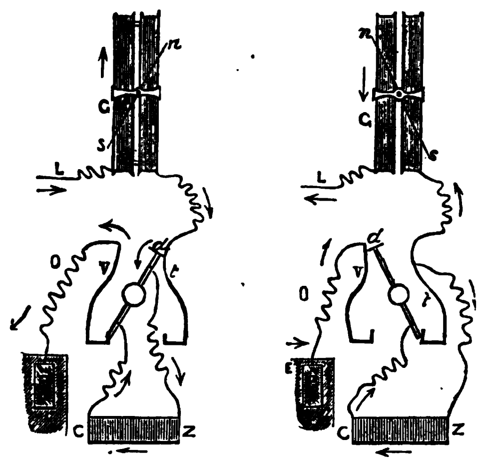


Fig. 52. Fig. 53.

to the distant station, where the instrument, as in *Fig.* 50, is ready to receive the signal. The needle is deflected, and the current returns through L, to the galvanometer coil, G, deflects the needle, and returns by the wire attached to the spring, *t*, and by the cross-piece, *d*, completes the circuit to Z. By moving the handle, H, to the right, as in *Fig.* 53, the direction of the current, and of course the deflection of the needle,

will be reversed. As soon as the signalling is finished, the cross-piece is restored to the position shown in *Fig.* 51, and the instrument is again ready for receiving signals.

By a little reflection it will be seen that the same motion of the needle is produced at the same instant, both at the sending and receiving station, so that the operator sees on his own instrument the same deflections as are taking place at a distant station, and all the galvanometers connected with the same wire will be similarly deflected (*Fig.* 54).

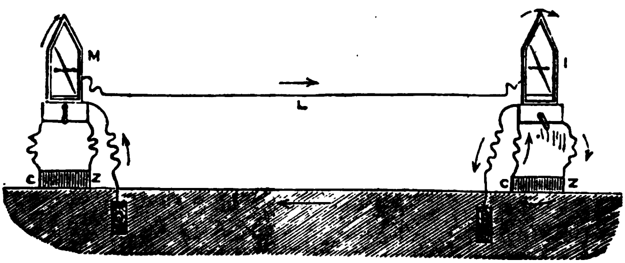


Fig. 54.

By an arrangement between the two operators a number of definite movements may be decided upon, which shall indicate letters. Two deflections of the needle to the right may be A; three in the same direction, B four, C; one right and one left, D; and so through the alphabet.

The instrument just described is called the single needle instrument, but by employing two needles a greater number and variety of signals can be forwarded in less time; but each needle requires a separate conducting wire, while the batteries may remain the same

A little inexpensive apparatus will make the principle of the telegraph easily intelligible to a class.

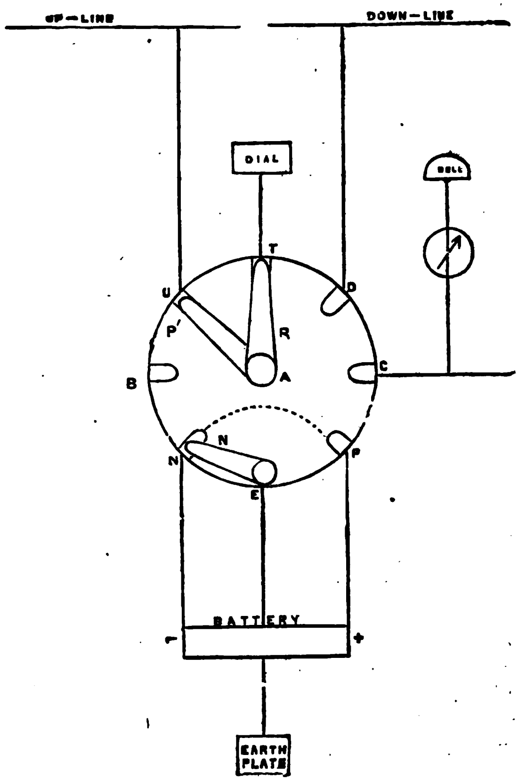


Fig. 55.

Current Reverser.—It is necessary to have means at hand, working instantaneously, for reversing the current. To effect this various contrivances are made use of. *Fig.* 55 will enable the student to understand one of the modes in use. The figure represents the back of an instrument, the pivot, A, is in connection with the handle seen at the front of an indicator.

First.—Suppose we wish to send a signal on the *up line.* Place index, *n,* upon N; R on P, and P′ upon U.

The current will flow from + to P, then across to U, along the up line to the earth-plate at the opposite end of the wire, and then to the earth-plate in the figure, afterwards to E, N, and the negative pole of the battery.

Second.—To transmit a current on the down line. Let the instrument be placed as before, with this exception,—move P′ to D. Then the current will flow from + to P, P to D, along the down line to earth-plate, back to earth-plate in figure, then to E, N, and the negative pole.

Third.—To reverse the direction of the current. Reverse the connections with the poles of the battery. For example, in the first case the current was sent along the up line and back through the earth-plates; now place *n* upon P, and R upon N. The course of the current will now be from + to P, P to E, to the earth-plate, then to the opposite earth-plate, along the up line to U, from U by P′, and then by R to N. It must be remembered that the studs T, D, &c., are of metal, and that the metallic wires are attached to them.

Measures of Current Strength.—Suspend a small magnetic needle with the voltaic circuit, and in the plane of the magnetic meridian. When the cur-

rent passes the needle will be deflected. The intensity of the current is proportional to the tangent of the angle of deflection. An instrument constructed for thus testing the intensity of the current is known as the *tangent galvanometer* (*Fig.* 56).

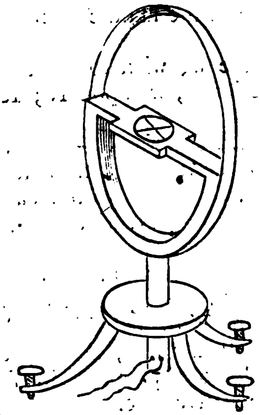


Fig. 56.

It consists of a strip of copper bent into a ring of about a foot in diameter. The ring is supported by a tripod. In the lower half of the ring is fixed a slight frame of wood, on which at the centre is placed the small compass needle with its graduated circle. The circle is placed in the magnetic meridian, the deflection of the needle is noted while the current traverses the copper strip, and then, on consulting a table of tangents, its value may be read off. This instrument is suitable for currents of low tension. For those of high tension the galvanometer multiplier is of more value.

Faraday's Voltameter is an instrument for ascertaining the strength of a current by means of the quantity of gases given off in a fixed time (*Fig.* 57).

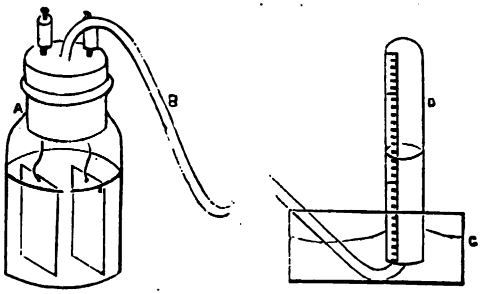


Fig. 57.

A is a wide-mouthed glass containing dilute H_2SO_4. Through the cork of A pass two wires carrying platinum plates, between which the current is made to pass. A bent tube, B, also passes through the cork, and leads the enclosed mixture of oxygen and hydrogen into C. The latter contains mercury, as also does the inverted test-tube, D. This tube is graduated, and tube, B, passing to its mouth, discharges the gases which pass to the top of D, expelling the mercury. The quantity of gases given off in a second may be read off, and thus the strengths of current may be ascertained and compared.

Conducting Wire.—If a piece of glass or other insulating body be introduced between the conducting wire and a magnetic needle, the deflection of the needle is not affected. The conducting wire not only affects a magnetized needle, but the wire itself displays magnetic properties. If a thin wire of some non-magnetic metal, say copper, be employed to complete

a voltaic circuit, such a wire will, for the time, attract iron filings, and the filings will be arranged in a uniform thickness around the circumference of the wire. When the circuit is broken by disconnecting the wires the filings fall, and the attractive power of the wire is instantly renewed on completing the circuit. The iron filings become small magnets, the poles of which are arranged alternately north and south around the wire.

This effect is best exhibited by the following experiment:—

Take a flat board or stout card, 8 or 10 inches square, and upon this construct a flat helix of copper wire, commencing at the centre, and coiling it round so as to keep the coils about half an inch from each other. The coils can be secured in their places if on wood by small wire staples, or if on card by a few stitches of thread passing through it. The inner end of the wire must pass through the centre of the wood or card, and must be of sufficient length to connect with one of the plates of a voltaic battery, whilst the other end of the wire is connected with the other plate.

The flat helix then becomes magnetized by the passage of the current, and the opposed faces of the successive coils are in opposite states of polarity. If a paper screen be laid upon the coil, and iron filings be sprinkled upon it, they will instantly arrange themselves into polar lines of magnetic force around each individual coil, thus showing in a most marked manner the position of the coil below.

In this experiment, however, the filings can only exhibit the effect taking place horizontally between the proximate surfaces of the wire, but it must be remembered that every portion of the surface of the wire is capable of the same polar arrangement of the iron filings.

A wire can only be looked upon as a vehicle for the transmission of the current, which, could it be supposed to flow independently of it, would exhibit the same phenomena. It is the practice to say that magnetism is developed at right angles to the conducting wire: this is not strictly correct, for magnetism is not developed at right angles to the axis, but in tangents to the circumference.

To understand this, let us imagine a conducting wire carrying a current of electricity. A piece of iron wire laid transversely across this conductor will constitute a tangent to its upper surface, and will take up the tangential magnetic effect due to the surface with which it is in contact.

Let us suppose that as it lies horizontally upon the conductor, its polarities are such that the right end is north and the left end south.

This relative arrangement of polarity will be maintained in every tangent that can be formed round the circumference of the conducting wire. For example, let the transverse iron wire have its right or north end slightly depressed, whilst the other end is correspondingly raised; it now forms a tangent to a new surface, but the respective polarities remain unaltered. Now depress the north end until the wire stands vertically on the right side of the conducting wire; the polarity is still unchanged, the north end being downwards and the south upwards. Continue the experiment by passing the transverse iron wire still further round the conductor, until it stands across beneath it. The north end is now on the left, and the south on the right side of the conducting wire, but they still maintain the same polarities. Their positions with regard to space are reversed, though with regard to any radius of the wire they are the same.

Go a step further, and bring up the north end of the wire on the left side of the conductor, and the upper end is still north, while the lower end is south. Lastly, bring the wire round to its original horizontal position over the top of the conductor, and matters are the same as when we commenced.

It is thus seen that every linear current is surrounded by a kind of atmosphere of magnetic influence, which appears to be circulating round it in planes at right angles to its axis, and always maintaining the same definite direction with regard to the course of the current itself.

It is necessary that the direction of the currents and the relative poles produced should be clearly understood; and to this end let us suppose that we have helices formed on glass tubes, so that soft iron rods can be introduced, as in *Fig.* 58. To make these spirals, hold the glass tube vertically, run the spiral downwards from *right* to *left* on the side nearest you. This will constitute a right-handed helix. If the downward direction be from left to right, the spiral is left-handed.

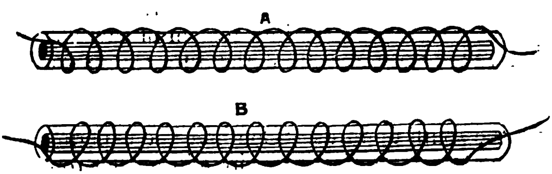


Fig. 58.

In a right-handed helix the south pole is at the end at which the current enters, and of course the opposite end is the north pole. In a left-handed helix the reverse is the case.

Whatever the direction of the current, however, the polarity is easily found by taking up the former *memoria technica*, and imagining yourself in the wire swimming with the current and looking at the axis of the spiral; *the north pole is always on the left.*

A bar may be magnetized by coiling round it an insulated wire and passing even a weak current, the result will be great magnetic power.

The Solenoid.—If a copper wire be formed into a ring, the ends of which are not closed, but are connnected with the terminals of a voltaic pair, the ring will exhibit polarity, not so much in the direction of its edges as on its faces, one face possessing south and the other north polarity. The effect of these polarities will be best seen by coiling a wire upon a round ruler so as to form a spiral of 3 or 4 inches in length. The ruler can then be withdrawn, and the extreme ends of the wire can be brought back either inside or outside the coil, so that the ends are near the middle of its length. The wire should be previously covered with silk or cotton, so as to allow of the coils being wound as closely as possible to each other. Such a spiral is termed a solenoid, and exhibits the following effects. Every coil represents a separate and independent ring, having one face north and the other south; and we find on examination, that just as the magnetic polarities are accumulated at the ends of a steel magnet, so they are also accumulated at the ends of the solenoid, which becomes itself a magnet built up of small magnetic planes.

This arrangement may help us to understand something of the magnetic transverse planes of which a steel magnet itself is theoretically composed.

If this solenoid, whilst conducting a current, be

placed in conditions in which it is free to move horizontally, it will arrange itself north and south precisely after the manner of a magnet, and its ends constituting its poles will be similarly attracted and repelled either by another solenoid or a steel magnet.

Since the current passing through the wire of the solenoid goes round and round in the same direction as that in which the wire is coiled, it is quite evident that if after a single layer of a given length has been coiled upon the ruler we go on coiling wire, not to increase length but thickness, by returning back over the same coil and forming a double thickness, the same relative direction of the current is preserved, and we have by this process doubled the number of the magnetic planes, all acting in the same direction. If now we go on coiling a third layer of wire back again over the second, this layer will have the same direction as the first, and so many more planes will contribute to the general effect. In this way we can multiply effects to an indefinite extent, since every plane is a unit added to increase the whole.

The Electro-Magnet.—If we take a solenoid of this description, which for convenience may be coiled upon a large bobbin having a hollow centre, we have the means of concentrating the magnetic effects by the introduction of a soft iron bar into its interior.

This, from its inductive susceptibility, serves to take up, distribute, and arrange, in their respective polar relations to each other, all the magnetic influences of all the coils by which it is surrounded, and this constitutes an electro-magnet. The attractive power of such a coil, when excited by a powerful battery, is something surprising. Let a bar of iron ½ inch in diameter, and 6 or 8 inches long, be supported in a

vertical position on a table, and let a coil of this kind be gradually brought down over the end of the bar. When it is depressed to a certain distance, which will vary according to the size of the coil and power of the battery, the iron bar will suddenly spring up from the table into the interior of the bobbin, and will be suspended, as it were, upon nothing, and may be made to dance up and down by communicating motion to it by the finger.

If into the solenoid just described we insert an iron bar, as large as it will admit, the bar becomes powerfully magnetic; one end being a north and the other a south pole, corresponding with the polarity of the ends of the solenoid, which will depend upon the direction in which the current is passing round. If the connection with the battery be suddenly broken, the whole of the magnetism disappears at once, and if the connections be reversed, the polarity is also instantaneously reversed.

If it be desired to exhibit the full effect of the attractive power thus produced, it is better to employ a bar, bent into the shape of a horseshoe, so that both poles may be brought to act upon the keeper or armature, which from the laws of induction, already described, will be much more powerfully attracted. *Fig.* 59 exhibits a powerful form of electro-magnet, fixed in a frame, to the armature of which there is a convenient arrangement for suspending any desired weight for testing the power of the electro-magnet or the strength of the exciting current; the poles of the battery are attached to the loose wires at the side, and as the magnet is of soft iron, the instant the current stops the magnetic power is at an end. In coiling wire upon a horseshoe, care must be taken to wind the wire upon the second leg, exactly in the same

direction as if it formed part of the straight bar, and had been bent subsequently to putting the wire on.

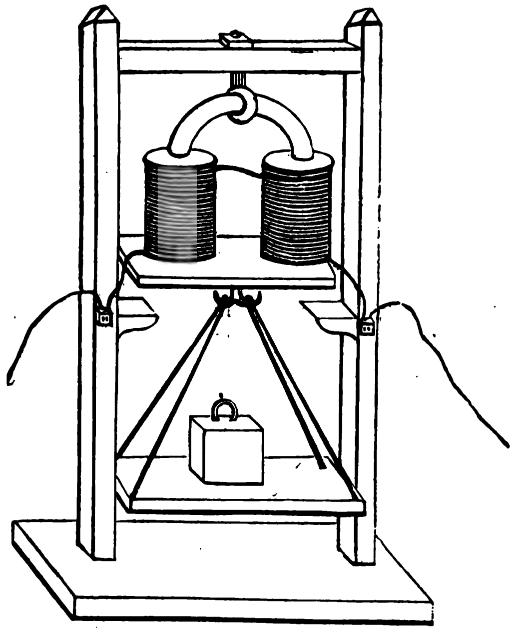


Fig. 59.

By this process electro-magnets have been made capable of lifting a ton or more.

The development of magnetism in iron, however, does not keep pace with the electrical influences which are brought to bear upon it, equal increments of electrical action not producing equal increments of

magnetic force. With small additions of electrical currents the magnetic development is in a higher ratio than the currents themselves. At a certain point they are about equal, but beyond this there is a rapid and enormous loss of effect, the iron appearing to reach a point of magnetic saturation.

Electro-magnetic Rotation.—We have mentioned that the deflective action of a conducting wire on a magnetic needle is a tangential one, or, in other words, the direction of the force is at right angles to the diameter of the wire. One pole of the needle is deflected to the right hand, and the other pole to the left; and on whatever side of the wire the needle is placed the same effect takes place. The tendency of this force, acting at every point of the circumference of the wire in the same direction, is to cause a rotation of the wire on its axis, and to communicate motion in an opposite direction to all magnets within its influence.

If the action of the current be confined to a single pole of the magnet, a continuous rotation of the pole round the conducting wire may be obtained; or if the magnet be fixed and the wire moveable, the wire will revolve round the magnet. The contrivance originally proposed by M. Ampère for causing a bar magnet to rotate on its own axis is very simple. The magnet, M (*Fig.* 60), is allowed to float in mercury, being kept in a vertical position by a weight of platinum, P.

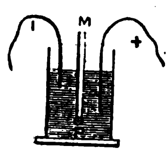


Fig. 60.

The action of the electric current is confined to one pole of the magnet by insulating the conducting wire, with the exception of its end, and introducing it vertically into the mercury to the depth of half the magnet. Another wire, connected with the negative pole of the

battery, just dips into the mercury to complete the circuit. The counteraction which would otherwise take place from the other pole is thus prevented, and the magnet turns slowly on its axis.

The wire may be shown to rotate by taking a glass tube (G G, *Fig.* 61) and closing the lower end with a piece of cork, through which a piece of soft iron wire is introduced, so as to project above and below. A little mercury is introduced so as to make a passage between the wire and the glass tube. The upper opening of the tube is also closed with a cork, through which a piece of copper wire, C, passes, terminating with a hook or loop. Another piece of wire is suspended from this loop, the end of which is amalgamated. In this arrangement a temporary magnet is made of the soft wire at the bottom of the tube by the voltaic current, and around this the moveable wire, W, revolves, changing its direction by changing the direction of the current.

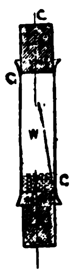


Fig. 61.

Molecular Changes.—When a bar of soft iron is made into a magnet, and when it is demagnetized, are conditions both of which are attended with molecular motion. The bar, on becoming magnetic, slightly increases in length, and suddenly contracts to its former dimensions when the magnetism ceases.

Ampere's Theory.—If a simple helix, made of thin wire, be freely suspended, and an electric current passed through the helix, it will arrange itself in the magnetic meridian; that is, it will point north and south, and be attracted and repelled by a magnet, just like an ordinary compass needle.

Ampère, who first pointed out the analogy between an ordinary magnet and a helix when conveying an

electric current, has deduced a theory of the connection between magnetism and electricity. He assumes that all bodies which exhibit magnetic polarity derive this polarity from currents of electricity which are perpetually circulating around the particles of which the magnetic bodies are composed. Around each particle an electric current is supposed to be continually circulating, and the direction of these currents is supposed to be uniform, each current circulating in a plane at right angles to the axis of the magnetic power. *Fig.* 62 shows these currents circulating

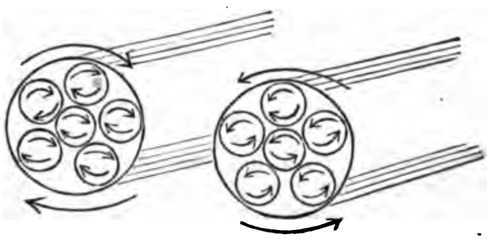


Fig. 62.

spirally round the particles; the inner currents, in opposing directions, neutralize each other, while the outer currents, having nothing to counteract them, give a resulting current, as shown in the figure. The resultant of these small currents would be equivalent to that produced by a single current twisting in a spiral direction uniformly around the bar, which would be in the axis of the helix. In an ordinary magnetic needle pointing north and south the currents would ascend on the western side, and descend on the eastern. No proof of these currents can be given, nor of their continuance in permanent magnets. The

mutual action between wires which convey currents and permanent magnets is easily understood.

Induced Currents by Magnets and by Currents.—Allusion has already been made to the fact that if a current of electricity be passed through a coil, as E F, *Fig.* 63, and a bar of iron or steel be inserted,

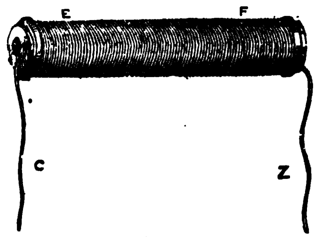


Fig. 63.

the bar will become a magnet. A simple experiment will establish the converse of this. Attach wire, C and N, to a galvanometer, or any measure of currents. Insert a magnet into the interior of the coil, E F, a current will pass through the coil at the instant of entry of the bar; again withdraw the bar, and a current in the opposite direction will be set up. Observe that the current passes only at the moment of entry or withdrawal of the bar. Further than this, the approach of the magnet will generate the current, as also its withdrawal.

The ordinary medical magneto-electric coil is constructed on the facts here noted. It consists essentially of a powerful horseshoe magnet, near to the poles of which a soft iron horseshoe bar is made to rotate rapidly by means of a multiplying wheel. The soft iron becomes a magnet when its ends approach the poles of the permanent magnet, and being sur-

rounded by spirals of insulated wire, currents are developed at the approach and withdrawal of the poles, and currents of such strength that when a person forms part of the circuit, which he may do by taking hold of two metallic cylinders, powerful shocks are felt, and the more so as the armature is removed from the steel magnet by means of a lever, so as to develop the full force of the magnetic power.

Browning, of London, who has done so much towards improving and extending the use of instruments for the illustration of popular science, has constructed instruments, moderate in cost, and at the same time even ornamental in appearance, in connection with this branch of science.

Fig. 64 will be readily understood from the previous explanation, and from the directions here given for using the instrument :—

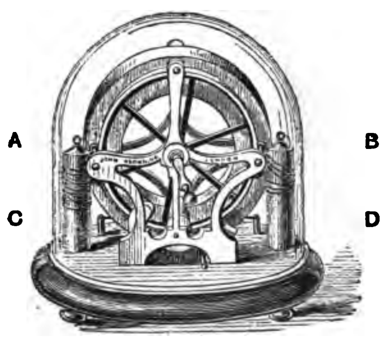


Fig. 64.

Take the hollow conductors, A B, off from the large studs on which they are placed ; uncoil the metallic cords which are wound upon them, and insert the

pins which are attached to the ends of these cords into the small holes which will be found in two upright brass studs at the back of the stand of the machine, marked C D in the diagram; then upon holding the hollow conductors, one in each hand, and turning the handle of the machine quickly, a strong electrical current will be felt.

A lever on the left of the machine, projecting beyond the frame, serves to move an iron feeder before the ends of the large circular magnet. By shifting this feeder the strength of the current given out by the machine can be regulated within any desirable limit. When the feeder is lifted up in front of the magnet, the current will be very feeble; when it is withdrawn quite below the magnet, it will be very intense.

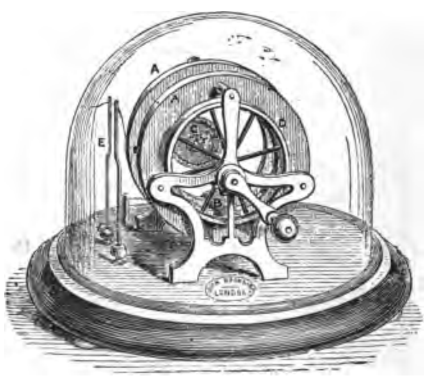


Fig. 65.

Machines of this kind, as usually made, are only powerful enough to produce physiological effects.

Those which have been made powerful enough to exhibit effects similar to voltaic batteries or plate-glass electrical machines have been so cumbersome and expensive as to preclude their coming into general use.

Fig. 65 illustrates a much more powerful instrument by the same maker.

A A are two permanent magnets of a circular form, whose poles at the lower part nearly approach, and actually face each other. B is an armature of soft iron, round which a quantity of insulated copper wire is wound lengthwise. The armature is made to revolve with great rapidity by the following arrangement :—The handle in front of the instrument communicates motion to the cog-wheels at C, which are a modification of Watt's celebrated sun-and-planet motion.

The wheel, D, moves with the cog-wheels, and being attached to a hollow arbor through which the spindle passes, to which the handle is attached, it makes six revolutions for one turn of the handle. The rim of the wheel, D, gives a multiplied motion to the armature, B, which is thus caused to revolve nearly thirty times for every time the handle makes one revolution.

The ends of the insulated wire on the armature are connected with the two brass balls in which the wires, marked E, are fixed. A commutator, which cannot be seen in the engraving because it is behind B, controls the connection in such a manner that all the positive currents are sent to one ball, and all the negative to the other.

Two armatures are supplied with each machine, one containing a few yards of insulated wire of large size; this is known as the quantity armature. The other armature contains a great length of exceedingly fine

insulated wire; this is the intensity armature. The quantity of armature produces effects similar to those produced by a voltaic battery; the intensity armature such results as are obtained by means of an electrical machine.

With the quantity armature the following effects can be produced :—Half an inch of platinum wire placed between the poles at E can be made white-hot in a few seconds. An induction coil may be made to give off bright sparks, or illuminate small induction tubes. Bells may be rung or telegraphs worked, even at a distance of many miles. Water or chemical salts may be decomposed.

With the intensity armature Abel's fuses may be fired, and most powerful physiological effects may be produced. The power of the shock current may, however, be modified, to an extent, at the will of the operator.

For any purpose the effects of a moderately powerful voltaic battery may be produced without the trouble and inconvenience attending the use of batteries.

Volta-electric Induction.—A wire under the influence of a voltaic current appears to exert some power on the electrical conditions of the bodies within its sphere, so as to put the electricity of these near bodies in motion if previously at rest, and if in motion, either to diminish or increase the current force. This effect, called volta-electric induction, is merely of a momentary character, and is only evident at the instant of completing or breaking the circuit. Experiment has shown that induced currents possess all the properties of electrical currents. Like them, they give sparks, produce violent shocks, decompose water and salts, and act upon magnetic needles.

Let the coil, *Fig.* 63, whilst in connection with a

battery, be brought near to a voltaic circuit. A current is instantly the result in the second circuit; and if the current in the primary coil be interrupted, a second but again momentary current is developed in the second wire. These two currents in the second circuit are called secondary currents. The secondary current, excited on making the primary circuit complete, is opposed in direction to the primary current, whilst on the withdrawal of the latter the secondary current is in the same direction. These secondary currents are called induced currents.

Holding the secondary spiral at a distance from the primary with the current flowing, approach the primary circuit to the secondary, and a current will be developed, as also the mere withdrawal of the primary helix will produce a current in direction as alluded to above. Two electric currents flowing in the same direction attract each other; if they flow in opposite directions they repel each other.

In addition to this, every change in the magnetic condition of bodies near a coil produces induced currents, and even an increase or diminution of magnetism will have as a result in the secondary circuit the reverse and direct currents

Ruhmkorff's Induction Coil.—Secondary currents, which are obtained by magnetic induction, have a high degree of intensity. If the circuit be broken while the current is passing, a brilliant spark will be observed at the point of interruption. An apparatus for exhibiting these secondary currents has been rendered very efficient by Ruhmkorff. Although there are different forms of this coil, they all consist essentially of two concentric helices of copper wire—the primary or inner coil consisting of a stouter and shorter wire than the secondary coil, which is made

of very long thin wire, insulated with silk; and each layer of coils is separated from the adjacent layers with an insulating varnish of gum lac. A soft iron cylinder is placed in the axis of the coil. In Ruhmkorff's 10-inch coil the inner or primary wire is 0·08854 inch thick and 132 feet long, 300 turns of wire being formed on the instrument. The outer secondary coil is 0·01312 inch thick and 26,246 feet in length, distributed in 25,000 coils. The primary coil is connected with the battery with binding screws. This primary coil is not continuous throughout. It is broken by a small armature of soft iron, to which a plate of platinum is attached on the under surface. As the primary current circulates through the inner or primary coil, the iron cylinder becomes magnetic and attracts the armature. The circuit is now interrupted; the current through the primary coil is immediately stopped; the magnetism of the iron wire ceases; and the armature, or hammer, as it is called, falls, and contact with the battery is immediately renewed; the hammer is again attracted, and immediately falls. Thus the magnet acts as a means of making and breaking the contact several hundred times in a minute. A powerful current is induced in the secondary coil by each of the momentary currents in the primary coil.

When an apparatus of this kind is put in motion by a battery of three or four cells, torrents of electricity in a high state of tension are evolved through the secondary coil; and when the two ends of the wire are brought within about one-eighth of an inch together, a succession of bright sparks pass between them.

Fig. 66 represents more in detail one of these coils. C is a vertical bobbin, about 12 inches high, standing

on a thick glass plate. The positive pole of the battery is connected with the wire, *p* G, and transmits the current by the conductor, E, to the commutator, D; it then passes by F to one of the extremities, *a*, of the primary thick wire of the bobbin; the other end ter-

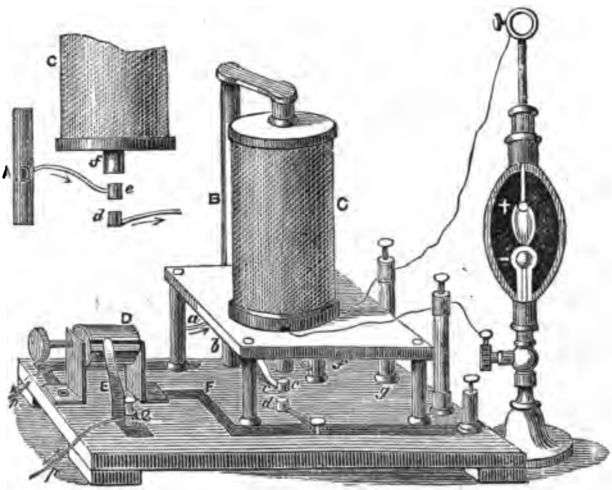


Fig. 66.

minates in one of the copper feet, *f*, which support the glass plate, and the current emerging from the bobbin passes to *c*, from which it reaches the iron column, *b* B; it then passes to the oscillating hammer, *e*, which is alternately in and out of contact with the conductor, B. When contact takes place the current passes to D, and returns to the battery by the wire, *n*. The oscillations of the hammer, *e*, are produced by a

cylinder of soft iron, *f*, or a bundle of soft iron wire placed in the axis of the bobbin. When the current passes through the thick wire the iron is magnetized, and attracts the hammer, *e*, which is also soft iron; the current is broken because the circuit is broken at *d*; the cylinder of soft iron loses its magnetism, and the hammer, *e*, again falls. The current then recommences, the piece, *e*, is again raised, and so on in proportion as the current passes intermittently on the primary wire of the bobbin, at each interruption, an induced current, alternately direct and inverse, is produced in the secondary wire; but as this is entirely insulated, the current acquires such an intensity as to produce very powerful effects. If the current be conducted to the upper and lower extremities of a globe, as represented in the figure, the electric light may be exhibited, and a series of other interesting experiments on light.

Ruhmkorff, in the arrangement of his coil, appears to have used a coating of cotton as the medium of insulation for his secondary coil; hence the tension exhibited at the secondary terminals, although very surprising, seldom developed a spark of more than half an inch in length.

Mr. Hearder, by covering a secondary wire with silk, and insulating the superposed layers from each other by a considerable thickness of oil-silk or gutta-percha, succeeded in obtaining sparks of from three to six inches in length, with not more than three to four miles of wire. Lately, however, the subject has been taken up by Ritchie in America, and Siemens and others on the Continent, as well as by experimenters in England, who have so modified and carried out the processes for insulating the secondary coil as to obtain sparks of twelve and even twenty inches in length. There is one essential portion of the induction coil

which requires some explanation, namely, the condenser, introduced by Fiseau.

This condenser consists of a very large surface of some thin non-conducting material, such as oil-silk, varnished or waxed paper, or some analogous tissue, coated on each side to within a short distance of the edge with tinfoil, after the manner of a Leyden jar, which it perfectly resembles. The employment of a second sheet of oil-silk over one of the coatings permits the arrangements to be rolled or folded into a small compass. Wires from these two coatings are connected with the primary coil at the part where the current is interrupted, so that when the interruption takes place in the primary wire, the ends thus disconnected from each other are still in contact, each with one of these two wires, which thus as it were complete the current through another channel. The secondary current, therefore, which under ordinary circumstances would have tension enough to pass over the interrupted interval and complete the circulation in the primary wire, is now diverted into another course, namely, the condenser. This one, however, does not complete the metallic circuit, but disposes of the current by employing it to charge these two large coatings; the tension is thus reduced sufficiently to intercept the passage of a very large portion of secondary current, thereby permitting the magnetic reaction of the iron core to exert its influence almost exclusively on the secondary coil, producing the high effects of tension before described. The induction coil is now becoming an instrument of the highest importance in spectrum analysis, from the facility with which its sparks disintegrate and volatilize very minute portions of the substances which form its electrodes.

Magneto-Electricity.—As the term electro-mag-

netism indicates the production of magnetism through the agency of electricity, so the term magneto-electricity implies the development of electricity from magnetic influence. The whole of the effects observed at the secondary terminals of an induction coil are due to electricity developed from the reaction of magnetism; and whether this magnetism be excited originally by electrical agency, or whether obtained at once from the influence of a permanent magnet, the effect is the same, differing only in degree.

It has been shown that whilst a current from the voltaic battery is passing round the bar in one direction, a secondary current is produced in the same wire by the reaction of the magnetism upon it, and passes in an opposite direction; so that the wire is actually carrying for the time two separate and independent currents at once in opposite directions. It has been explained that the secondary current is transient, and only occurs at the moment of the change of the bar from its neutral to its magnetic state; and that when this condition again changes by the suspension of the current of the battery, the sudden change from the magnetic to the neutral state produces another electrical wave, which is in opposition to the first.

To show that this is due alone to magnetic reaction on the wire coil, the voltaic coil must now be dispensed with, and the terminals of the coil be connected with a galvanometer. Matters being thus arranged, make the iron bar suddenly magnetic by bringing a powerful steel bar magnet quickly in contact with one end of it, which will thus magnetize it by induction. A current will instantly be produced in the coil, which flowing through the galvanometer will deflect the needle into a position which will show that the flow of electricity is in the inverse direction of that produced by connec-

tion with the battery; that is to say, if the battery pass round the bar in a right-handed direction, the current produced by the magnetism would be in an inverse one, or left-handed.

If the magnet be now suddenly separated from the bar, the immediate return of the latter to the neutral state produces a sudden electrical wave in the opposite direction, as will be indicated by the inverse deflection of the galvanometer.

If, instead of placing the magnet in contact with the iron bar, the pole of the magnet be merely made to pass by the end of it, hesitating slightly when they are both in the same line, the galvanometer will show the waves, one in one direction and the other reversely.

Again, the iron bar may be removed from the coil, and in its place the magnet itself may be inserted. The sudden presence of the magnetic influence produces the magneto-electric current through the coil, deflecting the needle accordingly, whilst the sudden withdrawal of the magnet produces the reverse wave and deflection.

Currents developed in this way are employed for a variety of purposes. They are made to take the place of voltaic currents in electrotype manipulations. They are employed for physiological purposes.

The Magnetic Telegraph Company employ contrivances of this kind to work their telegraphic instruments.

By far the most important application of this principle, however, is its employment for the production of the electric light, which is now successfully accomplished by the ingenious and beautiful contrivances of Mr. Wylde, which, however, are too complicated to be explained here.

Physiological Effects.—If the electrodes of a

powerful battery is held by the two hands, moistened with salt and water, which increases the conductibility, a shock is felt similar to that produced by the Leyden jar. The violence of the shock is in proportion to the number of elements employed. With a Bunsen's or Grove's battery, with 50 couples, the shock is very powerful; with 200 couples it is unbearable, and even dangerous. The human body is a bad conductor. The shock produced by the Leyden jar is due to the recomposition of the two electricities. With the Leyden jar the shock and the discharge are instantaneous. In the case of a battery the shocks rapidly succeed each other, because the battery after each discharge is immediately recharged. The action of a voltaic current on animals varies with its direction. If a current be sent through the ramifications of the nerves, a muscular contraction is experienced at the commencement, and a painful sensation when it ceases; but if the current is transmitted in the opposite direction, a sensation is produced as long as it continues, and a contraction of the muscles at the moment of interruption. These effects, however, are only produced by feeble currents. With intense currents the contractions and painful effects (no matter in what direction they may be transmitted) occur on closing or breaking the current. By powerful currents rabbits which have been suffocated for half an hour have been restored to life. All the vital actions, some time after death, may be reproduced in dead animals, but they are only of a temporary character, and cease with the transmission of the current.

The Extra Current.—When a current is sent through a single primary coil a secondary current in an opposite direction is excited in *this same* coil. Break the circuit, and a secondary current flows in the

same direction as the primary current. In the first case the primary current is lowered by the secondary current; in the second case the two act together, and as a consequence the spark given in breaking the primary current is much more brilliant than the one given on closing the circuit. It is to this induced current in the primary circuit alone that the term extra current is applied.

Again, the secondary current, when flowing, reacts upon the primary, weakening its effect, and the primary current likewise affects the secondary current. Complete the primary circuit, and the secondary current will be enfeebled. At the moment of breaking the first circuit the secondary current regains its full power, and it is for this reason that in Ruhmkorff's coil we obtain the currents of greatest strength in one direction only.

Heat, Resistance, and Current Strength.—The strengths of currents may be estimated by the amount of metal destroyed as well as by the gases produced. This destruction, also, of metal—or rather, change into a salt—develops a constant amount of heat, which is distributed in the battery or in the exterior circuit. If we connect the poles of the battery by means of a thick wire of good conducting material, the heat will be formed in the battery itself, but on changing for a fine wire, a non-conductor, the energy of the electro-motive force will be expended in overcoming the resistance, and the heat will be found in the exterior circuit.

The heat depends also on the strength of the current—in fact, it is proportional to the square of its strength. Represent the strength of two currents by the numbers 2 and 4, then the heat developed will be as 4 is to 16.

Again, the heat generated is proportional to the electrical resistance of the wire through which the current passes.

Silver is a much better conductor of electricity than platinum. Pass currents of equal strength through wires of these two metals of the same thickness and length. The platinum will become red-hot, while the silver only feels warm.

Derived Currents.—In *Fig.* 67 the current from a Bunsen's element traverses the wire, A B C. Let a second wire, S M, be attached to the first, then the current will be divided at N, which, with P, are the points of derivation, and wires N S M and N B P are derived wires, along which partial or derived currents

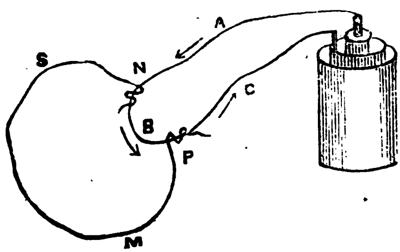


Fig. 67.

flow: the original current may be called the primitive current, and the two derived currents are named the principal current, which is stronger than the primitive, insomuch as the resistance to the current is less, as two paths are provided. The laws of derived currents are—

First: *The intensities in the divided parts are equal to the intensity of the principal current.*

Second: *The intensities of the divided currents are inversely as their resistances.*

Wires of the same length and section would divide the current equally. Wires of the same length, but of different sections, would divide the current unequally, and the quantity which traversed each wire would be proportional to the sections.

GLOSSARY.

Terms used in the Science of Magnetism.

Agonic Lines.—Lines of no variation of declination, or lines in which the magnetic and geographical meridians coincide. There is one passing through Asia, another through America.

Armatures, or Keepers.—Pieces of soft iron, which react on the poles of magnets, and thus prevent loss of the magnetic force.

Artificial Magnets.—Steel bars which have had the magnetic property imparted to them by artificial means.

Astatic Needle.—An arrangement of magnetic needles which is not affected by the magnetism of the earth.

Austral, or Southern Magnetism.—The magnetism exhibited by that end of a freely suspended magnet which points to the south magnetic pole.

Boreal, or Northern Magnetism.—The magnetism exhibited by that end of a freely suspended magnet which points to the north magnetic pole.

Coercive Force.—The force which resists the decomposition and recomposition of the magnetic fluids.

Compensators.—Expedients by which the errors of the mariner's compass needle arising from the attractions and repulsions of magnetic substances in a vessel are corrected.

Consequent Poles, or Consecutive Points.—Sometimes a magnet has more than two poles; those lying be-

tween its extreme points are called consequent poles, or consecutive points.

Diamagnetic Substances.—Those substances which are *repelled* by powerful electro-magnets.

Earth's Magnetic Equator, or Aclinic Line.—The line round the earth upon which the dipping needle remains in a horizontal position.

Gymbals.—The pivoted hoops which support the box of a mariner's compass.

Horizontal Intensity.—The intensity of the earth's magnetic force exerted upon a needle in the horizontal direction.

Horseshoe Magnet.—A magnetic bar bent into the form of a horseshoe.

Inclination, or Dip.—The angle which the magnetic needle makes with the horizon. In the northern hemisphere the north pole is depressed, in the southern the south pole.

Isodynamic Lines.—Lines connecting together places of equal magnetic intensity; they resemble in their general arrangement, but do not exactly coincide with lines of equal dip.

Isogonic Lines.—Lines of equal declination.

Magnet (from Magnesia, in Asia Minor).—A body possessing the property of attracting iron, steel, nickel, cobalt, and chromium.

Magnetic Axis.—A straight line passing through the poles of a magnet.

Magnetic Battery, or Compound Magnet.—A number of magnets joined together side by side by their similar poles.

Magnetic Curves.—The curved lines into which iron filings will arrange themselves on a cardboard beneath which a powerful magnet is placed.

Magnetic Declination, or Variation.—The angle which

a magnetic meridian forms with a geographical meridian. (At London the angle is 18°.)

Magnetic Induction.— The development of magnetism by magnetic action at a distance.

Magnetic Meridians.—Lines on the earth's surface corresponding with the direction in which the magnetic needle points.

Magnetic Parallels, or Isoclinic Lines.—Lines of equal dip.

Magnetic Polarity.—That property in a magnetic needle which causes it when freely suspended to turn always the same pole towards the same point on the earth's surface.

Magnetic Poles.—The points in a magnet towards which the greatest attraction is exerted.

Magnetic Saturation.—The limit to which a magnetic body can be magnetized. It may be magnetized beyond this point, but will soon return to the point of saturation.

Magnetic Storms.—Simultaneous perturbations of the magnetic needle in different places.

Natural Magnet, or Loadstone.—A natural oxide of iron possessing magnetic properties.

Neutral Point.— The middle point of a magnet, where no attraction is exhibited.

North Magnetic Pole of the Earth.—A point on the earth's surface 70° N. lat., and 96° 43′ W. long., where the dipping-needle takes a vertical position, with its N. pole downwards.

Paramagnetic Substances.—Those substances which are *attracted* by powerful electro magnets.

Sources of Magnetism.—Influence of magnets, ter restrial magnetism, and electricity.

South Magnetic Pole oj the Earth.—A point on the earth's surface 75° 30′ S. lat., 154° E. long., where the

dipping-needle takes a vertical position, with its S. pole downwards.

Terrestrial Magnetism.—That part of the science which treats of the magnetic force exerted by the earth.

Torsion Balance.—An instrument for measuring the intensity of magnetic attraction and repulsion by their effect in twisting a wire.

Total Force.—The resultant of the horizontal and vertical forces acting on a magnetic needle.

Vertical Intensity.—The intensity of that component of the total force which acts in a vertical direction.

Terms used in the Science of Electricity.

FRICTIONAL ELECTRICITY.

Analogous Pole.—That pole (or extremity) of a crystal which shows positive electricity when the temperature is rising.

Antilogous Pole.—That pole (or extremity) of a crystal which shows positive electricity when the temperature is falling.

Brush Discharge.—The divergent luminous cone formed by the continuous flow of electricity from or to a point.

Conductors.—Those bodies which allow the electricity imparted to them to flow freely from one part to another. The worst conductors are those which offer the greatest resistance to the passage of electricity; the best conductors are those which offer least resistance.

Dielectrics.—Those bodies which allow induction to take place through them, as glass, air, &c.

Dissimulated.—Held by inductive influence.

Electrical Discharge.—The passage of electricity from one body to another placed near it.

Electrical Induction.—The action of an electrified body exerted at a distance upon the electricity of another body.

Electrical Pendulum.—Any light conductor suspended by an insulator.

Electric Battery.—A series of Leyden jars whose internal and external coatings are respectively connected.

Electricity (from *electron*, amber).—The science which treats of the laws of attraction and repulsion exhibited by bodies under certain circumstances.

Electro-dynamics.—The science which treats of electricity in a state of motion.

Electrometer.—An instrument for measuring the strength of an electrical charge.

Electrophorus.—A circular cake of resin or shellac between two metal discs, the upper one being moveable, and having an insulating handle, and the lower one communicating with the ground.

Electroscope.—An instrument for detecting the presence of electricity in any body.

Electro-statics.—The science which treats of electricity in a state of rest.

Excited (*or Electrified*) *Body.*—A body in which electricity is developed by friction, heat, &c.

External Armature.—The outside metallic coating of a Leyden jar.

Free Electricity.—Electricity which is not held by inductive influence.

Glow Discharge.—The pale blue light seen on a conductor when the electricity, owing to the high tension, is escaping into the air.

Good Examples of Induction.—Electrophorus, condenser, Leyden jar, fulminating pane.

Insulated.— Surrounded by non-conducting substances.

Insulators.—Bad conductors of electricity.

Internal Armature.—The inside metallic coating of a Leyden jar.

Lateral Discharge.—The discharge which takes place through imperfect conductors connected with conductors of electricity.

Leyden Jar.—A glass jar, coated inside and out with tinfoil nearly to the brim, and having a projecting knob fastened to the inner coating.

Non-conductors.—Those bodies which do *not* allow the electricity imparted to them to flow freely from one part to another.

Phenomena of Electrical Discharge.—Physiological, luminous, mechanical, magnetic, and chemical.

Positive and Negative Electricity.—Two different forms of electricity existing in an unelectrified body; when an electric is excited, it becomes positively or negatively electrified, according to the nature of the rubber or the body rubbed.

Proof-plane.—A slender rod of glass or shellac with a small disc of copper-foil at the end. Its use is to convey electricity from any charged conductor to an electrometer for the purpose of testing the strength of the charge.

Pyro-electricity.—Electricity developed by heat, as in tourmaline.

Reservoir of Electricity.—The earth is called the common reservoir of electricity on account of its size, and because all electricity is finally discharged into it.

Residual Charge.—The feeble charge found to be present in a Leyden jar after discharge has taken place.

Return Stroke.—The name given to the shock perceived when induction ceases, owing to the discharge of some electrified body near it.

Striking Distance.—The distance through which a discharge takes place.

Tension.—The force with which electricity accumulated on the surface of a body tends to escape.

VOLTAIC ELECTRICITY.

Crown of Cups.—A combination of voltaic couples.

Daniell's Battery.—A voltaic arrangement, the conducting liquid of which is sulphate of copper, and arranged so that secondary currents are prevented by the deposition of copper on the copper plate.

Deflection of Magnetic Needle.—The turning of a magnet out of the magnetic meridian under the influence of a voltaic current.

Direction of Current.—The direction in which the positive electricity passes.

Electro gilding.—The process of giving a coating of gold to an object, by making it the negative pole in a cell containing a solution of chloride of gold and cyanide of potassium, a plate of gold being used as the positive pole. In electro-silvering the bath consists of cyanide of silver and cyanide of potassium.

Electrolytes.—Substances capable of being decomposed by an electric current.

Electrolysis.—The decomposition of such substances by means of an electric current.

Electro-magnet.—A soft iron bar in the shape of a horseshoe, with an insulated copper wire coiled round the two branches in opposite directions.

Electro-magnetism.—That branch of physical science which treats of the mutual action of magnets and currents.

Electro-metallurgy.—The art of precipitating metals from their solutions by the slow action of a voltaic current.

Electro-motive Force.—The force of the voltaic currents produced by the contact of two dissimilar metals in a conducting fluid.

Electro-motive Series.—A series of metals arranged according to the energy with which they are attacked when put into an acid solution. The principal metals have been arranged as follows:—zinc, cadmium, tin, lead, iron, nickel, bismuth, antimony, copper, silver, gold, platinum, graphite.

Galvanic Pair, or Voltaic Couple.—An arrangement consisting of two plates of dissimilar metals connected together by a wire, and placed in some acid solution: when the wires are not in contact the couple is said to be *open;* when connected it is said to be *closed.*

Galvanometer, or Reometer. — An instrument for measuring the strength of a voltaic current by its effect in deflecting the magnetic needle.

Induced Currents.—Instantaneous and momentary currents developed in metallic conductors under the influence of other currents passing through wires placed near them, or under the influence of powerful magnets.

Inducing Currents.—Those which give rise to induced currents.

Ions.—The constituents into which an electrolyte resolved by a voltaic current.

Negative Electrode, or Cathode.—The terminal points of the wire proceeding from the positive plate of a voltaic battery.

Negative Element.—That constituent of an electrolyte which moves *against* the current.

Negative or Collecting Plate.—The plate in a

voltaic couple which is least attacked by the acid solution.

Phenomena of Voltaic Electricity.—Physiological, chemical, mechanical, and physical; the last term including thermal, luminous, and magnetic effects.

Polarization of Electrodes.—A term applied to the condensation of the constituents of an electrolyte upon the electrodes, thus producing secondary currents.

Poles, or Electrodes.—The terminal points of the wires proceeding from the voltaic battery. In electrolytic processes they are the points at which the current enters and departs.

Positive Electrodes, or Poles.—The terminal points of the wire proceeding from the negative plate of a voltaic battery.

Positive Element.—That constituent of an electrolyte which moves *with* the current.

Positive, or Generating Plate.—That plate in a voltaic couple which is most vigorously attacked by the acid solution.

Reoscope, or Multiplier.—An instrument for multiplying the deflecting force of a simple current of electricity upon a magnetic needle.

Secondary Currents.—Currents produced in voltaic batteries in an opposite direction to the primary current by a deposition of zinc on the copper plate.

Tension of Battery.—The tendency of the electricity accumulated at the poles to escape; it is proportional to the number of couples, while the quantity is proportional to the surface of the plates.

Thermo-electric Couple.—Two pieces of dissimilar metals joined at one end and connected at the other by wires through which the current passes when heat is applied to the points of junction of the metals.

Thermo-electricity.—Electricity developed by heat.

Voltaic Current.—The continuous flow of electricity resulting from the chemical action which takes place in a voltaic battery.

Voltaic or Galvanic Electricity.—That form of electricity developed by chemical action.

Voltameter.—An instrument for measuring the strength of a voltaic current by its effects in decomposing water. Another form of voltameter measures the strength of the current by its heating effects.

Volta's Pile.—A series of discs, piled up in the following order :—zinc, wet cloth, copper; zinc, wet cloth, copper; and so on. A wire connects the zinc at the bottom with the copper at the top.

EXAMINATION QUESTIONS, MAY, 1872.

MAGNETISM AND ELECTRICITY.

General Instructions.

You may select either the first paper or the second paper, but you must confine yourself entirely to the paper you select.

You are only permitted to attempt eight questions.

These eight questions may be selected from the first paper, or from the second paper, in the proportion stated at its head, but not from both.

If these rules are not strictly observed the candidate's paper will be cancelled.

The same value is attached to the correct answer of each question.

Three hours are allowed for this examination.

N.B.—A full and correct answer will in all cases gain more marks than an inexact or incomplete one.

First Stage, or Elementary Examination.

1. A magnet is broken in two, describe the magnetic conditions of its parts.
2. State the grounds of the belief that the smallest particles of a magnet are themselves perfect magnets.
3. The marked end of a magnet is attracted by the earth's north magnetic pole; but if the magnet be set floating on a cork it does not move towards the pole. Why?
4. If upon a warm board a dry sheet of paper be rubbed with india-rubber it is electrified. How is this proved?
5. Show by a simple experiment that the electricity developed on resin by the friction of flannel is different from that developed on glass by the friction of silk.
6. Describe Franklin's plate and explain its action.
7. A strip of paper rubbed with india-rubber is brought near a glass rod which has been rubbed with silk; what follows?

Deduce from the experiment the quality of the electricity upon the paper.

8. Explain fully what takes place when light bodies are attracted by a stick of sealing-wax rubbed with flannel.
9. If a strip of pure platinum and pure zinc be immersed in acidulated water, and caused to touch each other, bubbles of gas are seen rising from the platinum, but not from the zinc. Explain this effect.
10. You are required to prove that a current of electricity is passing through a telegraphic wire to which you have access. How would you do it?
11. If a strong voltaic current is sent in succession through a thin platinum wire through acidulated water, and then through a wire which surrounds a common poker, what is the effect produced in each case?
12. What is the part played by nitric acid in Grove's battery?
13. Explain what you understand by the direction of a voltaic current.

Second Stage, or Advanced Examination.

INSTRUCTIONS.

Read the General Instructions at the head of the Elementary paper.

You are only permitted to attempt eight questions.

You may only select two in magnetism, three in frictional electricity, and three in voltaic electricity.

The value attached to each question is the same.

---

20. Show by a sketch the curves which are formed when iron filings are scattered over a bar magnet.
21. A bar of iron is held vertical, and a magnetic needle is passed slowly from its bottom to its top; describe the action of the iron upon the needle. What is the effect of reversing the bar?
22. You have two bar magnets of different powers, and a small magnetic needle. You are required to determine and express numerically the relative powers of the two magnets. How will you do it?
23. A stick of sealing-wax is fused on to a thin plate of brass;

using the sealing-wax as a handle the brass plate is placed upon a sheet of vulcanized india-rubber which has been struck by the brush of a fox; what is the condition of the plate? You touch the plate and lift it; what is now its condition?

24. Two insulated metal spheres are united by a chain, a body positively electrified is placed near one of them; what is the condition of the other? You touch the sphere adjacent to the electrified body; what occurs? Finally, you remove the electrified body; what occurs?
25. You are required to electrify a brass rod by the friction of flannel. How will you do it?
26. A burning pastile placed upon the prime conductor of an electric machine glows more brightly when the machine is turned. Why?
27. A needle is attached to the prime conductor of an electrical machine. Why is it that the sparks are shorter than when the needle is absent?
28. You wish to convert a poker into an electro-magnet, with its knob as a north pole. Show by a sketch how it is to be done.
29. The north pole of a magnet is plunged downwards into a metallic ring. Show by a sketch the direction of the current induced in the ring. What occurs when the magnet is withdrawn?
30. What is the meaning of the *extra current?* Describe some of its effects.
31. Describe, and illustrate by an example, the process of electrotyping.
32. The same electric current is sent in succession through two spirals of platinum wire. Both feel warm to the hand. You then heat one of the spirals to bright redness with a spirit lamp. What is the effect upon the temperature of the other?

First Stage, or Elementary Examination, 1873.

INSTRUCTIONS.

You are only permitted to attempt eight questions.

You may select only two in magnetism, three in frictional electricity, and three in voltaic electricity.

The value attached to each question is the same.

1. A steel sewing needle is drawn over the north pole of a magnet from eye to point; what is the subsequent condition of the needle? The point is presented to the north end of a mariner's compass needle; what occurs?
2. Supposing you break the sewing needle referred to in the last question in two, and present the two ends of each half in succession to the north end of a mariner's compass needle; what occurs?
3. What do you understand by the polarity of a magnet?
4. You carry with you a dipping-needle from the earth's north magnetic pole across the equator to the south magnetic pole; how will the dipping-needle behave during this excursion?
5. I hold a dry glass rod, which has been rubbed with silk, near a brass ball, which is supported on a dry glass stand; what is the state of the ball? Supposing the stand which holds the brass ball to be moist instead of dry; what will occur?
6. Two strings are given to you, and you are required to test whether they insulate or conduct electricity; how will you do it?
7. Two brass balls, supported on glass stands, are united by a chain; a stick of sealing-wax rubbed by flannel is brought near one of the balls; what is the condition of the other?
8. You touch the ball furthest from the sealing-wax; remove your hand, and then remove the sealing-wax; what is now the electric condition of the two balls and the chain? You must state what occurs at each step of the process.
9. You are required to charge and discharge a Leyden jar; how will you do it?
10. There are two kinds of electricity, called positive and negative. You rub sealing-wax with flannel; are both electricities excited, or are they not? If both, where? If only one, where?
11. I place a bit of silver on my tongue, and a bit of zinc under it, and cause the two pieces of metal to touch each other; what occurs? Describe some means of proving that an electric current is generated.
12. A voltaic current is sent through water, the water is decomposed, and two gases are formed; what are they, and where do they make their appearance?
13. A current means something flowing. What is it that flows in the voltaic current? is it anything that you can see, or feel, or taste, or smell? If not, what proof have you of its existence?

14. Give a sketch of a cell of Grove's battery, and state the uses of its various parts.
15. The same current from a Grove's battery is sent through two pieces of wire, one of silver, the other of platinum, of the same length and thickness. The silver remains cool, the platinum is heated to redness; why?

Second Stage, or Advanced Examination.

Instructions.

Read the General Instructions at the head of the Elementary paper.

You are only permitted to attempt eight questions.

You may only select two in magnetism, three in frictional electricity, and three in voltaic electricity.

The value attached to each question is the same.

---

21. Place two bar magnets side by side, parallel to each other, with their north poles turned in the same direction; show by a sketch how iron filings scattered over the two magnets will arrange themselves.
22. Five balls of iron hang in a series from the north end of a magnet, but you cannot get a sixth ball to hang; why? The north end of a second magnet is brought *over* that of the first; seven balls of iron now cling together; why? You place the second north pole *below* the series of balls; several of them fall away; explain this.
23. A small magnetic needle freely suspended, and acted upon by the earth alone, executes 120 vibrations in a minute; placed near the pole of a steel magnet it oscillates 250 times in a minute; compare the force which the earth exerts upon the needle with that exerted by the magnetic pole, and give the numbers which express the forces.
24. A magnetic needle is placed oblique to the magnetic meridian; show by a sketch the character of the forces acting upon the needle, and tending to turn it into the meridian.
25. A plate of metal insulated from the earth is connected with the conductor of the electric machine; a quarter of a turn of the machine charges the plate to 80_0 of an electrometer. A second plate, not insulated, is now brought close to the first, so that a very thin layer of air separates them. It now

requires a whole turn of the machine to charge the plate to 80°; explain this.

26. State, as far as you know, wherein the charging of a submarine electric cable resembles the charging of a Leyden jar.
27. What is meant by the law of inverse squares as applied to electric attractions? State the precise conditions under which the law holds good.
28. You are required to charge a Leyden jar by means of an electrophorus; how will you do it?
29. Give an explanation of thunder and lightning, embracing the phenomenon known as the return shock.
30. A glass cell contains a solution of common table salt, coloured by indigo. A voltaic current is sent through the solution; the blue colour is observed to grow gradually paler, and finally to disappear; explain this effect.
31. Describe Davy's mode of decomposing potash and soda; and give a description of the two metals which were obtained from these non-metallic substances.
32. In the common medical coil there is usually an iron core surrounded by a thick wire, and around this is a bobbin of fine wire, to which handles are attached. Now this fine wire is wholly detached from the thick one, and also from the exciting battery; how, then, are shocks experienced when the two handles are grasped and the machine set in action?
33. You are required to coil a wire, and to suspend it so that the axis of the coil, when a voltaic current is sent through it, shall set like a magnetic needle in the magnetic meridian. Show by a sketch how this is to be done.
34. You are required to devise an experiment which shall prove that electric currents flowing in the same direction attract each other, while currents flowing in opposite directions repel each other.

First Stage, or Elementary Examination, 1874.

INSTRUCTIONS.

You are only permitted to attempt eight questions.

You may select only two in magnetism, three in frictional electricity, and three in voltaic electricity.

The value attached to each question is the same.

1. In what direction does the mariner's compass point in London?
2. Can you obtain a magnet with a single pole? Give the experimental grounds of your answer.
3. You are required to magnetize a sewing-needle so as to make the eye end of the needle a north pole; how will you do it?
4. You are required to demonstrate the law that like magnetic poles repel, and that unlike poles attract each other; how will you do it?

---

5. A collodion balloon simply stroked with the hand becomes negatively electrified. Supposing you were asked to prove the truth of this statement, how would you proceed?
6. An egg-shell is placed on a table, and a glass rod which has been rubbed with silk is brought near the shell: the shell rolls after the rod. Describe the condition of the rod and the shell during the motion of the latter.
7. You are required to prove by experiment the electrical law that bodies similarly electrified repel, and that bodies dissimilarly electrified attract each other: how will you do it?
8. Describe the Leyden jar, and the mode of charging it.
9. Describe the electrophorus and the mode of charging it.

---

10. Tell me what you understand by chemical combination and chemical decomposition, illustrating your answers by reference to the formation and decomposition of water.
11. Give me a good example of chemical combination and decomposition brought about by one and the same voltaic current.
12. What is your notion of a voltaic current?
13. Give me a clearly described example of the magnetic action of an electric current.
14. I give you platinum, zinc, and brine, and ask you to produce by means of them an electric current: how will you do it?

Second Stage, or Advanced Examination.

21. You hear of the magnetic meridian and of the geographical meridian. What is the difference between them? To what changes, if any, have they been observed to be subject?
22. The end of a magnetic needle brought near the middle of a bar magnet is, to all appearance, not acted on at all by the magnet. Does the magnet really exercise no action on the needle in this position? If so, what action?
23. Faraday constantly used the term "lines of force" as applied to magnetism; how are these lines visibly represented? Draw them as they exist round a straight bar magnet.

---

24. Describe an experiment to prove that when a Leyden jar is charged with positive electricity, positive electricity escapes from the outer coating of the jar.
25. Describe an experiment by which a second jar could be charged by the positive electricity thus escaping.
26. State the principal points of difference between frictional electricity and voltaic electricity; and also describe arrangements by which the action of the one may be caused to resemble more and more the action of the other.
27. Describe the action of a pointed lightning-conductor on a cloud charged with positive electricity.
28. The action of chronometers is said to be sometimes deranged by a discharge of lightning; how do you suppose this to occur?

---

29. Describe the rheostat, and the manner in which it is applied to determine the resistance of different kinds of wire.
30. A glass bulb filled with a weak solution of proto-sulphate of iron and immersed in water is strongly attracted by a magnet; the same bulb immersed in a concentrated solution of the proto-sulphate is as strongly repelled; explain this.
31. Pure water under some circumstances offers a powerful resistance to the passage of a voltaic current; describe an arrangement by which even a weak current can be sent

through water. State the principles which guide you in your answer.

32. Give some examples of secondary chemical action brought about by a voltaic current.

33. Two voltaic currents are sent in opposite directions round the same magnetic needle ; the needle points to zero : what do you infer? One of the currents passes through and heats a platinum wire. On blowing upon this wire and cooling it the needle immediately starts aside: explain this.

EXERCISES.

1. Let a magnetic needle, which oscillates 15 times a minute under the influence of the earth's magnetism, be brought near to a bar magnet, it is found to oscillate 40 times per second ; the same needle is found to oscillate 24 times per second at the same distance from another magnet ; what are the relative strengths of these magnets?
2. If the number of oscillations of a magnetic needle per minute at two places on the earth's surface are 13 and 16, what is the relative intensity of terrestrial magnetism at these places?
3. A magnet is introduced into a torsion balance, and produces a torsion of 20° in the wire ; what must be the power of a magnet as compared with this, which will produce a torsion of 60°, neglecting the earth's influence?
4. It has been found that to deflect a magnetic needle one degree from its meridian requires a torsion of 35° of the wire of the torsion balance; let a magnet be introduced which produces a deflection of 20_0, how many degrees of torsion will be required to bring the middle back to 10°?
5. A charge of electricity is imparted to the ball in a torsion balance which repels the shellac needle, with its ball, through an angle of 24° ; how many degrees of torsion will be required to move the needle from 24° to angles of 12° and 6° respectively?
6. A charge of electricity being imparted to the ball in a torsion balance, the needle is deflected 64; how many complete turns of the upper dial-plate will be required to bring the needle to 8_0?
7. The needle in a torsion balance is held against the attraction

of the ball at an angle of 30° by a torsion of 360°; what amount of torsion will be required to hold it at 60°?

8. A current of electricity is passing from north to south in a wire; how must a magnetic needle be placed so that its north pole will be deflected to the east?

9. A compass needle placed under a wire of the electric telegraph is deflected to the west; in what direction is the wire laid? and is the current passing northward or southward?

10. A and B are the poles of a battery, of which A is east and B west, the wire which joins them of course being east and west: if we find that a magnetic needle placed under the wire is reversed in position, which of the poles of the battery may we conclude is positive?

11. A current is passing from London to York; place a magnetic needle under the wire: will the N.P. deflect E. or W.?

12. Between Manchester and Glasgow I place the needle under a telegraph wire; when a current passes the needle deflects west; is the current passing to the north or to the south?

13. The current passing from N. to S., the needle is above the wire; in what direction is the deflection?

ANSWERS.

1. 4 : 1 nearly. 2. 2 : 3 nearly. 3. 9 : 1. 4. 2880°; 8 complete turns in upper dial. 5. 84° and 378°. 6. 11·38. 7. 450°. 8. Above the wire. 9. N. and S.; to N. 10. A. 11. West. N. 12. To N. 13. W.

Teachers will oblige by forwarding to my private address, St. John's Hill, Wandsworth, any suggestions or additions to this Work.

List of Necessary Apparatus in teaching the Science of Electricity.

This apparatus is to be obtained of M. Jackson, 65, *Barbican (opposite the Aldersgate Street Railway Station), who will forward a complete Price List of Scientific Apparatus and Pure Chemicals, post free, on application.*

No.	Article	£	s.	d.
106	Glass tube, one-half roughened, to show the difference in the kind of electricity from the different surfaces	0	3	6
107	Stick of lac, or of pasteboard well covered with lac, or of vulcanite	0	1	6
108	Plate electrical machine, 18 in. diameter at least	4	15	0
109	Amalgam . . . oz.	0	0	6
112	Battery of six Leyden jars, of at least quart size, arranged so that they may be used either separately or together	1	18	0
116	Faraday's butterfly net, to show that electricity is distributed on the external surface of a conductor	0	1	6
118	Brass chain, six yards . . . per yd.	0	0	6
122	Leyden jar, with moveable coatings	0	10	6
123	Jointed discharger, with insulating handle	0	5	6
125	Electrophorus of vulcanite	0	10	6
127	Six simple zinc and copper elements with wires	0	2	0
128	One Daniell's cell, twelve inches high. 1 quart	0	7	0
129	One Smee's or Walker's pair	0	6	0
132	Galvanometer multiplier, needle vertical	0	18	0
139	Apparatus to show electrolysis of water	0	8	6
141	Copper wire coated with cotton, No. 16, two lbs., @ 3s.	0	6	0
142	Ditto, No. 32, two lbs., @ 8s. 6d.	0	17	0

Additional List of Apparatus—Electricity.

No.	Article	£	s.	d.
110	Pith balls . . . doz.	0	0	6
111	Unspun silk.			
113	Quadrant electrometer	0	4	0
114	Gold-leaf electroscope with condenser	0	12	6

		£	s.	d.
115	Roll of tinfoil on roller, insulated, and capable of being wound or unwound by an insulating handle, or silk cord working like a roll blind	0	10	0
117	Conductors of different forms of wood covered with tinfoil, to show distribution of electricity and experiments on induction	0	6	0
120	For heavy things, thick sheets of gutta-percha are convenient insulators.			
121	Fulminating pane of glass, gutta-percha, or vulcanite	0	6	0
124	Glass vessel, mounted so that it may be exhausted with the air-pump, to show the discharge in rarefied air or gases	1	5	0
126	Whirl of pointed wire	0	2	6
130	Four lbs. mercury for amalgamating zinc plates, &c. . . . . lb.	0	4	6
131	Ten-celled Grove's or Bunsen's battery . . .	4	10	0
133	Pencils of gas-carbon . . . . . each	0	0	6
134	Fine wires of iron, copper, and platinum, for deflagration	0	3	0
135	Henley's universal discharger, with holders for carbon electrodes or metal wires	1	5	0
136	Bent wire capable of rotating about an axis in its own plane, for showing the neutral action of electric currents	0	10	0
137	Magnet capable of rotating about a current parallel to it	1	0	0
138	Barlow's wheel, or Sturgeon's	0	7	0
140	Three V tubes for showing electrolysis .@ 4*s*.	0	12	0
143	Chain of alternate links of platinum and silver, to show unequal heating effects of a current in the two metals	0	6	6
144	Six binding screws to screw into blocks of wood to connect apparatus	0	3	0
145	Solenoid.			
146	Floating battery, carrying solenoid	0	4	6
147	Astatic conductor, in form of a double parallelogram of wire, to be adapted to the floating battery.			
148	Induction coil to illustrate electro-dynamic induction	0	18	0
149	Bobbin of wire to show induction by magnets .	0	6	0
150	Faraday's rotating needle	0	7	6

		£	s.	d.
151	Magneto-electric machine	1	7	0
152	Thermo-electric pair of bismuth and antimony, V shaped, for connecting with a galvanometer .	0	7	6
153	Apparatus to show the currents of electricity produced in a copper disc rotating between the poles of a magnet	1	11	6
154	Model of a single-needle telegraph . . .	0	10	6
155	Rheocord for illustrating electrical resistance .	1	5	0

LIST OF APPARATUS USED BY DR. GUTHRIE, ROYAL SCHOOL OF MINES, IN HIS LECTURES TO SCIENCE TEACHERS ON EXPERIMENTAL PHYSICS IN THE SUMMER OF 1870.

	£	s.	d.
Brown paper.			
Feathers.			
2 lb. of glass tubes (1s. 2d.) . .	0	2	4
Scissors . . .	0	1	0
½ lb. mercury. .	0	2	3
2 lbs. zinc (sheet) .	0	2	8
½ lb. tin (3s.) . .	0	1	6
Florence Flask .	0	0	3
Lath.			
Clothes brush.			
Shellac . . lb.	0	1	3
Methylated Spirit, pt.	0	0	10
Bunsen burner .	0	1	6
3 ft. of india-rubber tubing @ 8d. .	0	2	0
Paper (foreign post).			
India-rubber.			
Pestle and mortar .	0	1	6
Small Hessian crucible	0	0	1
Retort stand . .	0	2	6
Pliers (wire) . .	0	2	6
Wooden Desk.			
Knitting-needle.			
Silk tape, china ribbon	0	1	6
2 sticks of sulphur .	0	0	2
	1	3	10

	£	s.	d.
Piece of Flannel.			
Sealing-wax . .	0	0	2
Large india-rubber tubing. . .	0	1	6
Sheet vulcanized india-rubber . .	0	6	0
Book of gold-leaf .	0	2	0
Rough glass . .	0	0	2
Wooden support . .	0	0	1
Thin copper wire .	0	0	6
Silk cord . .	0	0	3
Unspun silk . .	0	2	0
Glass tumblers .	0	2	9
Leaden pipe . .	0	0	6
Small bolt-head .	0	2	0
Copper wire . .	0	1	6
Tinfoil . . .	0	1	6
Tin plate.			
2 wooden balls.			
20 lbs. sulph. acid .	0	3	4
10 lbs. fuming nitric acid . . .	0	6	8
1 sht. parchmt. paper	0	0	4
2 steel bars . .	0	6	0
These, and			
4 Grove's cells .	1	16	0
2 lbs. soft iron bar .	0	0	8
4 yds. bell wire (16).	0	0	6
1 lb covrd. copperwire	0	3	0
Glass for Leyden jar	0	0	1
Tin for Leyden jar .	0	0	2

LIST OF ADDITIONAL APPARATUS FOR EXPERIMENTS.

	£	s.	d.
Electrical Machines, Cylinder—			
Cylinder, 7 inches long	1	6	0
Ditto 10 " "	1	14	0
Ditto 11 " "	2	2	0
Electrical Machines, Plate 15 inches	3	18	0
Electrical Apparatus—			
Brass Balls—			

in.	⅜	½	⅝	¾	⅞	1	1¼ in. diam.
price	2*d.*	3*d.*	4*d.*	5*d.*	6*d.*	8*d.*	10*d.* each.

	£	s.	d.
Conductors (Brass) each, 3/-, 4/6, 5/6, 7/6, and .	0	10	6
Cylinders for machines—			

	6×3½	6½×4	7×5	8×5½	10×6	11×7
price	1/8	2/6	3/6	4/-	5/-	7/- each.

	£	s.	d.
Dischargers, plain, 2/-, 3/-, jointed, 5/6 and . .	0	6	6
Do. Henley's Universal	0	18	0
Glass rods for Pillars, &c. . . . . per lb.	0	1	0
Insulated Stools, each 5/6 and	0	7	6
Leyden Jars, 1 pint 3/6, 1½ pints 4/6, 2 pints . .	0	6	0
Do. Diamond, 1 pint 5/6, 2 pints . . .	0	8	0
Tin foil . . . . per lb.	0	3	6
Turned Wood handle and caps for Cylinder, per set	0	2	6
Electrical Experiments—			
Aurora Flask, 5/6; Bells, set of 3, 5/6, of 5 on stand	0	14	0
Of 8 tuned (Gamut)	1	12	0
Bird on Stand	0	4	6
Bucket and Syphon	0	2	0
Egg Stand	0	5	6
Figure Plates 5/- and	0	7	6
Hand Spiral	0	3	0
Do Revolving	0	7	6
Head of Hair	0	3	0
Orrery	0	4	0
Phosphorus or Spirit Cup, 6/- and	0	7	0
Pith Ball Stand	0	3	0
Pith Figures . . . . each	0	0	9
Pistol	0	4	0
Sportsman	0	14	0
Thunder-house	0	6	0

	£	s.	d.
Galvanic Apparatus—			
Batteries, Bichromate, half-pint 9/-, 1 pint . . .	0	12	6
Do. Bunsen's 6 in. Carbon 5/-, 8 in. do. .	0	7	0
Do. Daniell's 1 pint 5/-, 1 quart	0	7	0
Do. Grove's 9/-, in trays of 4 36/-, do. 6 .	2	14	0
Do. Smee's 6/- ,, 6	1	15	0
Battery Cells, Bunsen's Earthenware . . each	0	0	8
Do. do. Grove's and Smee's, Wedgewood Ware or Glass	0	1	0
Do. do. Porous—			

in. long	2	3	4	5	6	7	8	9	10	12	in. long.
price	2*d.*	3*d.*	3*d.*	3*d.*	4*d.*	5*d.*	6*d.*	7*d.*	8*d.*	1/4	each

	£	s.	d.
Porous, Flat, for Grove's, $4\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{2}$.	0	0	5
Battery Screws, each 6*d.*, Clamp Screw for Smee's, 8*d.* &	0	0	10
Coil Machine for Shocks, &c., with Handles, 12/6, 18/- and	1	4	0
Coil Machine with Battery, Directors, &c., for medical use, in polished Teak-wood Case .	2	5	0
Coils, Induction, Ruhmkorff's, to give spark—			

in. long	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	in. long.
price	20/-	40/-	63/-	each.

	£	s.	d.
Do. do. Vacuum Tubes, each 2/6, 3/6, 4/6, and	0	6	6
Commutators . . . . each	0	9	0
Copper Wire covered with Cotton—			

No.	16	18	20	24	28	32	36	
No. of ft. to lbs.	70	128	220	420	960	1,300	3,800	
price	3/-,	3/-,	3/6,	4-,	6-,	8/6,	12/6	per lb.

	£	s.	d.
Copper Wire covered with Silk, No. 16, 9/- per lb. No. 36	0	18	0
Decomposing Water Apparatus, each 3/6, 8/6, and	0	12	6
Electric Light Carbon Holders, per pair . .	0	6	0
Do, on Stand, with Rackwork	0	12	6
Electro-Magnets—			

in. diam.	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1	in. diam.
price	2/6	4/-	7/6	12/-	each.

	£	s.	d.
Electrotype Apparatus, complete 1 quart . .	0	3	0
Galvanometers . . . . each	0	6	0
Do. with Glass Shade, very delicate, 21/- and	1	10	0
Magnets, Horseshoe, each 3*d.*, 6*d.*, 1/-, 1/6, 3/-, 4/-, 6/- . . . . and	0	7	6

Bar—in. long	6	8	10	12	in. long.
price	2/-	3/-	4/6	5/6	per pair.

INDEX.

J. AND W. RIDER, PRINTERS, LONDON.